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NEAR TERM HYBRID PASSENGER VEHICLE DEVELOPMENT PROGRAM, PHASE I

CONTRACT NUMBER 955188

FINAL REPORT

APPENDICES A & B

OCTOBER 1979

PREPARED BY

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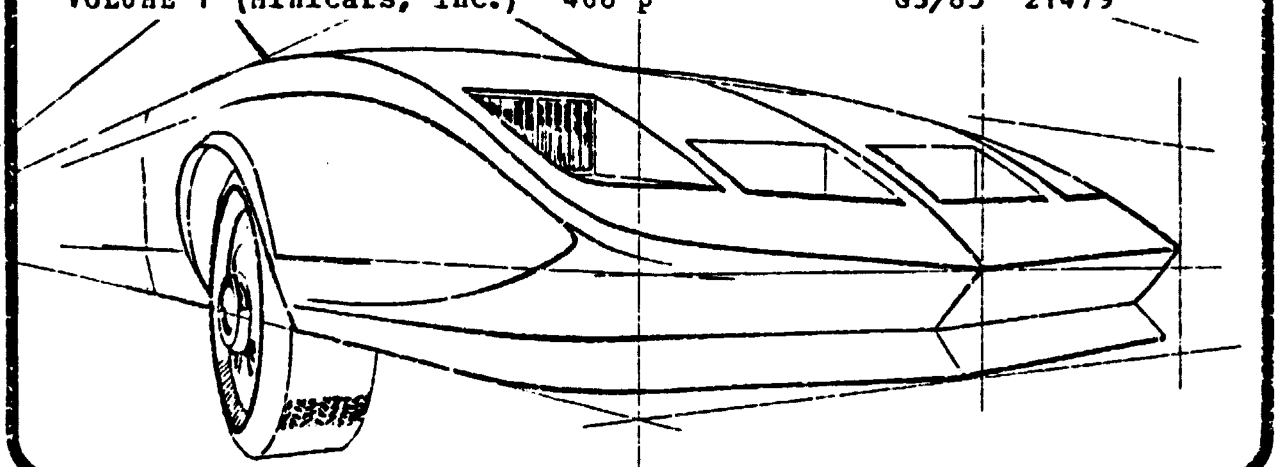

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JUN 1980

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APPENDIX A

MISSION ANALYSIS AND PERFORMANCE
SPECIFICATION STUDIES REPORT

VOLUME I

NEAR TERM HYBRID PASSENGER VEHICLE DEVELOPMENT PROGRAM

PHASE I

CONTRACT 955188

MISSION ANALYSIS AND PERFORMANCE SPECIFICATION STUDIES REPORT

VOLUME I

25 JANUARY 1979

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SUBMITTED TO:

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SUMMARY

In this report vehicle use patterns or missions are defined and studied. The three most promising missions were found to be

	Mission	Primary Reason for Selection
A	All-purpose City Driving	Maximum potential market penetration
BB	Commuting	Two-passenger car*
C	Family & Civic Business	Minimal range requirements

The mission selection process was based principally on an analysis of the travel patterns found in the Nationwide Transportation Survey (Reference 4) and on the Los Angeles and Washington, D.C. origin-destination studies data presented by General Research Corporation in Volume II of this report. Travel patterns in turn were converted to fuel requirements for 1985 conventional and hybrid cars. By this means the potential fuel savings for each mission were estimated, and preliminary design requirements for hybrid vehicles were derived.

*Does not meet JPL constraints.

DISCUSSION AND INTERPRETATION

The objective of Phase I of the Near Term Hybrid Passenger Vehicle Program is to design a hybrid passenger vehicle which has the maximum potential for reducing petroleum consumption in the near future, and to specify the missions for which the vehicle is to be used. This last is called the "Mission Analysis." Obviously the mission analysis and vehicle design are almost inseparable, as the choice of the best vehicle depends on its mission, and the mission depends on the vehicle to be used.

For this reason the present report must be viewed, to some extent, as preliminary. More definitive results can only be achieved once the conclusions of the Design Trade-off Studies and Sensitivity Analyses — which are now in progress and scheduled for completion in mid-year — become available and are fully integrated into the study. The mission analysis presented here gives mission requirements as intended, but the interpretation of these requirements can only be fully accomplished in the light of hybrid vehicle design capabilities and costs.

Conceptually, in mathematical parlance, the study is in effect a constrained optimization problem. The objective function to be minimized is petroleum consumption and the constraints, defined at length by JPL in Reference 1, concern the minimal levels of passenger capacity, performance, comfort, safety and public acceptability. These constraints are so tight that for some otherwise promising missions either no feasible solution will exist or the solution will be non-optimal. Our general approach has been to emphasize the optimal constrained solution, but also to consider what may happen if the constraints are relaxed.

The phrase "maximum potential for reducing petroleum consumption" implies both how much fuel <u>could</u> be saved (a question amenable to analysis) and how much fuel <u>will</u> be saved (which in part must remain a question of judgment). The first refers to the fuel that would be saved if a certain type of hybrid passenger vehicle (HPV) were to take over a certain portion of the auto market. The second must also consider the likelihood that the HPV will, in fact, achieve a certain level of customer acceptance.

In this report we estimate the potential fuel savings, given a certain level of customer acceptance. We hope to have more to say about the acceptance level when the characteristics of actual si ns (particularly cost, reliability and performance) more closely identified.

th t the vehicle meets the performance and comfort levels ied by JPL and the range and reliability requirements ir d by the mission, engineering and design analyses, the ri ble in determining acceptability will be cost. Cost must erpreted in the very broadest sense and must be related s cial and economic circumstances which may obtain in, say, riod from 1985 to 2000. Future circumstances which deter- he background of studies are often called "scenarios." f he more obvious scenarios are

. The price of gasoline and diesel fuel reaches what today would be considered astronomical levels, say $10 per gallon.

. Gasoline is rationed or becomes totally unavailable except to certain sectors of the population (for example, doctors).

. Each family is restricted to one car, or there is some other method of car rationing.

f these possibilities should be rejected out of hand. The ii g that is certain about the future is that it will be ent. It may be radically different.

study, however, we consider a scenario much like the t. It includes only the relatively minor variations speci- y JPL in Reference 1. We believe, nevertheless, that it is ant to keep radically different circumstances in view. A hi ch takes into account only one possibility cannot be te

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MISSION DEFINITION

As requested by JPL, our study is based on the concept of a mission, defined as "the required use pattern of a vehicle." We shall amplify and interpret this definition and shall describe our approach for selecting preferred missions.

The basic idea of the analysis by missions is, of course, to uncover and define some subset of the automobile market particularly suited to hybrid vehicles. A better name for it would be "market analysis." It goes without saying that missions do not provide the only way to subdivide the market. Much more commonly one thinks of automobile types, such as station wagons, family sedans or sports cars, or of customer characteristics, such as young "swingers," suburban middle income family heads of household, and so on. One can also characterize market sectors by engineering performance characteristics — as is done, for example, by Friedman (Reference 2), who classifies cars by their weight to power ratio — and in any number of other ways.

We must plan to integrate the results and methods of all approaches to automobile market analysis with our mission analysis, whenever possible. There are several excellent reasons, however, for making the missions approach our central theme.

1. It was specifically requested by JPL (Reference 1).

2. The best available statistics relating to auto travel have been broken down by trip purpose and, therefore, by mission.

3. Missions can be combined into new missions in a systematic and organized manner.

Surber and Deshpande (Reference 3) define missions as combinations of trip purposes. Trip purposes, in turn, are defined by enumeration by the U.S. Department of Transportation, Federal Highway Administration (FHWA), in Reference 4. Table 1 lists trip purposes and presents some preliminary notions of their characteristics.

Items 1 through 4 in Table 1 are the major trip purpose categories. We have broken out Item 5 — a subtopic of Item 4 in the FHWA study — as a separate category because of its unique requirements.

Table 1. Trip Purposes and Their Attributes

Trip Purpose	Frequency (%)		Approximate Daily Range Requirement (km)	Number of Passengers	Cargo Requirements	Performance
	Trips	Travel				
1 Home to work and return	36	42	100	2	low	medium
2 Family business	31	19	50	4	medium	low
3 Civic, educational, religious	9	5	50	4 to 6	medium	low
4 Social and recreational	22	33	100	4 to 6	medium	medium
5 Vacation	1	2.5	500	4 to 6	high	high

The range requirement numbers in Table 1 are essentially illustrative. Actual range distributions are calculated later in this analysis.

Initially it is unnecessary, and probably unwise, to categorize missions too rigidly. We know that any ultimately selected mission is some combination of the five items of Table 1. Our method is, therefore, to make detailed requirements and trade-off studies for each of the five trip purposes of Table 1, and then to sort the results into missions. However, we list here some sample missions in order to illustrate the mission concept further:

Mission S1	All-purpose family travel. This includes Trip Purposes 1 through 5.
Mission S2	Commuting to work. Trip Purpose 1.
Mission S3	Family business I. Trip Purposes 2 and 3.
Mission S4	Family business II. Trip Purposes, 2, 3 and 4.
Mission S5	Commuter and family business. Trip Purposes 1 through 4.

No one would claim that a person who purchases a car for a particular mission, say S2, will never use that car for other purposes. Rather, the idea is to proceed as if the customer thinks primarily of Mission S2 to provide him with the optimal car. We will then judge the market penetration and the petroleum savings attainable, and modify our results by making allowance for the fact that the car will be used for other missions as well.

Conceptually a mission may be defined by

$$S_i = \sum_j a_{ij} T_j \quad , \qquad (1)$$

where S_i is some attribute of Mission i, T_j is the same attribute for Trip Purpose j, and a_{ij} is a set of weighting factors, for which

$$0 \leq a_{ij} \leq 1 \quad \text{and} \quad \sum_j a_{ij} = 1 \quad .$$

This is, in general, the method used in the following sections.

METHODOLOGY

In accordance with Subtasks 1.1 through 1.3 of the Minicars Proposal to JPL (Reference 5), we will begin by calculating the amount of fuel (petroleum) which will be used to accomplish Trip Purposes 1 through 5. These calculations will be made for a variety of vehicles, including the conventional cars of the 1985 fleet (specified by JPL, Reference 6), a reference vehicle representative of the conventional car(s) which a hybrid vehicle might replace, and a set of hybrid vehicles of varying electric range. From these data we will calculate the total petroleum saved when hybrid vehicles replace conventional vehicles. The figures for the total petroleum saved tell us how much petroleum is saved when all vehicles (the entire fleet) engaged in a given trip purpose are replaced by hybrid vehicles. That is, it tells us the "maximum potential fuel saving." If this value is not substantial, there is no use in going further.

The calculations of fuel saved by replacing a set of reference vehicles by hybrids provide a more reasonable, and lower, value. This value is more nearly representative of what might be accomplished in reality, for the hybrid is assumed to replace only a targeted portion of all cars. The procedure will be repeated for each trip purpose, and the trip purposes then combined into missions. The end result is the determination of a (small) set of preferred missions and the characteristics of the car best suited to each.

The principal characteristic at this stage of the study is electric range. Some missions will not require as much electric range as others, and, since range is so critical for vehicles with electric propulsion systems, it should be possible to isolate these missions and design a vehicle to fit them. Our study shows that these ideas are sound.

This methodology can be conveniently divided into two tasks: first, the distribution of daily travel is determined for each trip purpose; second, the corresponding amount of fuel used is calculated for both conventional and hybrid vehicles. These analyses are presented in the next two sections of this report.

DAILY TRAVEL DISTANCE DISTRIBUTION

The distribution of the daily travel distances may be obtained either by combining the distribution of trip length with that of daily trip frequencies, or directly from origin destination surveys, as was done by General Research, Volume II of this study.

Trip length distributions for Trip Purposes 1 through 4 are shown in Figure 1. The figure demonstrates that the distributions of Trip Purposes 2 and 3 are nearly the same, as are those of 1 and 4.

Figure 1 also shows that the functional forms of the distributions for various travel purposes are closely similar, although, of course, the parameters differ. This is confirmed in Table 2. If, for brevity, we call the 99th percentile the longest trip, we observe from Table 2 that, for all trip purposes,

a. Seventy-five percent of all trips are shorter than 0.2 times the longest trip.

b. The longest trip is 5 times the average trip, and thus 75 percent of all trips are shorter than the average trip.

For vacation travel no distribution data — only the average distance traveled — have yet been found. Accordingly, the last column of Table 2 shows an estimate of the distribution of vacation travel distances. This estimate was made under the assumption that the distribution's functional form follows that of the other four trip purposes. The results appear to be reasonable. Of course, many of the longer trips will take more than one day.

We next consider the questions of trip frequency and daily travel. For trips to work, there are almost always two trips per day, five days a week, and no trips the other two days. It seems reasonable to assume that each commuter travels the same distance to work each day during a particular week, and that things do not change drastically from one week to the next. The average number of commuter trips per driver per day on this mission is thus 10/7 = 1.42, which checks the value given in Reference 4. The distribution of daily travel for this mission is thus easily found by multiplying trip length distributions by 2. The results are presented in Table 3. It appears, for example, that 95 percent

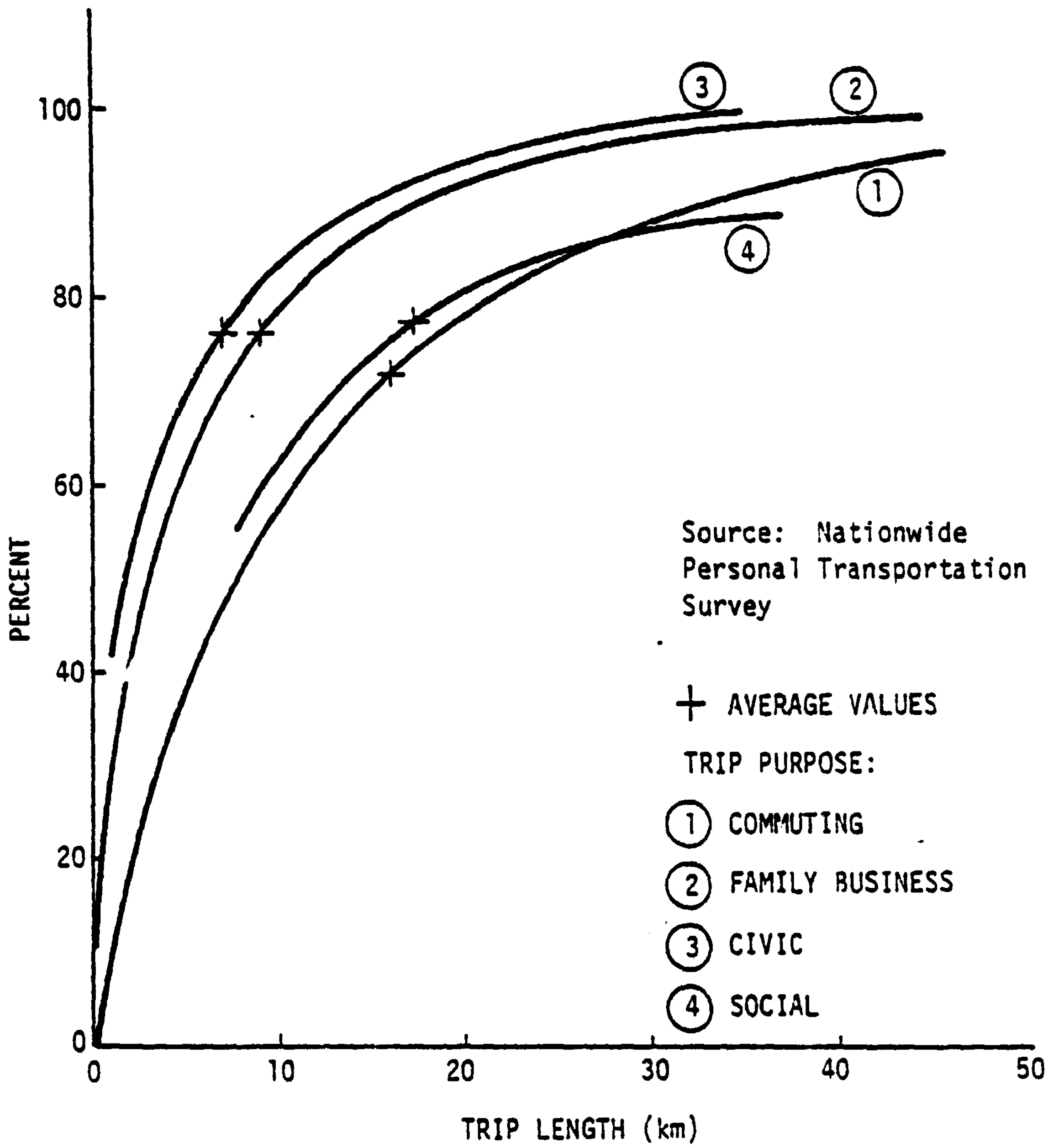

Figure 1. Distribution of Trip Length

Table 2. Further Analysis of Trip Length Distributions

	COMMUTE TO WORK Average Trip 16.3 km					FAMILY BUSINESS Average Trip 9.0 km				VACATION Average Trip 252 km	
	Interval (km)					Interval (km)				Interval (km)	
Decile	x_1	x_2	$\frac{x_1 + x_2}{2}$	$F(x_2)$	$P(x)$	x_1	x_2	$F(x_2)$*	$P(x) = F(x_2)-F(x_1)$	x_1	x_2
0-.1	0	8.3	4.2	.52	.52	0	4.5	0.6	0.6	0	128
.1-.2	8.3	16.7	12.5	.74	.22	4.5	9	0.76	0.16	128	256
.2-.3	16.7	25	20.1	.83	.09	9	13.5	0.84	0.08	256	384
.3-.4	25	33.3	29	.89	.06	13.5	18	0.90	0.06	384	512
.4-.5	33.3	41.7	37.5	.94	.05	18	22.5	0.93	0.03	512	640
.5-.6	41.7	50	46	.95	.01	22.5	27	0.95	0.02	640	768
.6-.7	50	58.3	54	.96	.01	27	31.5	0.96	0.01	768	896
.7-.8	58.3	66.7	63	.97	.01	31.5	36	0.97	0.01	896	1024
.8-.9	66.7	75	71	.99	.01	36	40.5	0.98	0.01	1024	1152
.9-.99	75	83.3	79	.99	.01	40.5	45	0.99	0.01	1152	1280

*F(x) denotes the distribution function.

Table 3. Distribution of Daily Range Requirements (Commuter Trips)

x = km/day	P(x)	F(x)
8.4	0.52	0.52
25	0.22	0.74
40	0.09	0.83
58	0.06	0.89
75	0.05	0.94
92	0.01	0.95
108	0.01	0.96
126	0.01	0.97
142	0.01	0.98
158	0.01	0.99

of all commuters drive a distance of 92 km or less each working day, and that the probability that the total commuting distance is somewhere between 25 and 40 km is 0.09.

For Trip Purposes 2 through 5, the trip frequency will behave more nearly like a random variable. Trip frequencies are available from General Research Corporation (Volume II) but are not relative to missions as we define them. They are commonly assumed to be Poisson distributed (Reference 7), and this is also the method which we use initially to investigate them. As Appendix A shows, however, this is only a relatively crude approximation to actual trip behavior. In subsequent sensitivity analyses we will examine more complex models if it is judged that their inclusion will affect the overall study results.

Daily range distributions for all passenger travel were calculated by Schwartz (Reference 7) under the assumption of an annual travel of 16,386 km per year per car and an average daily trip length of 14.3 km, which yields an average of 3.14 trips and 45 km per day. His results are presented in Figure 2.

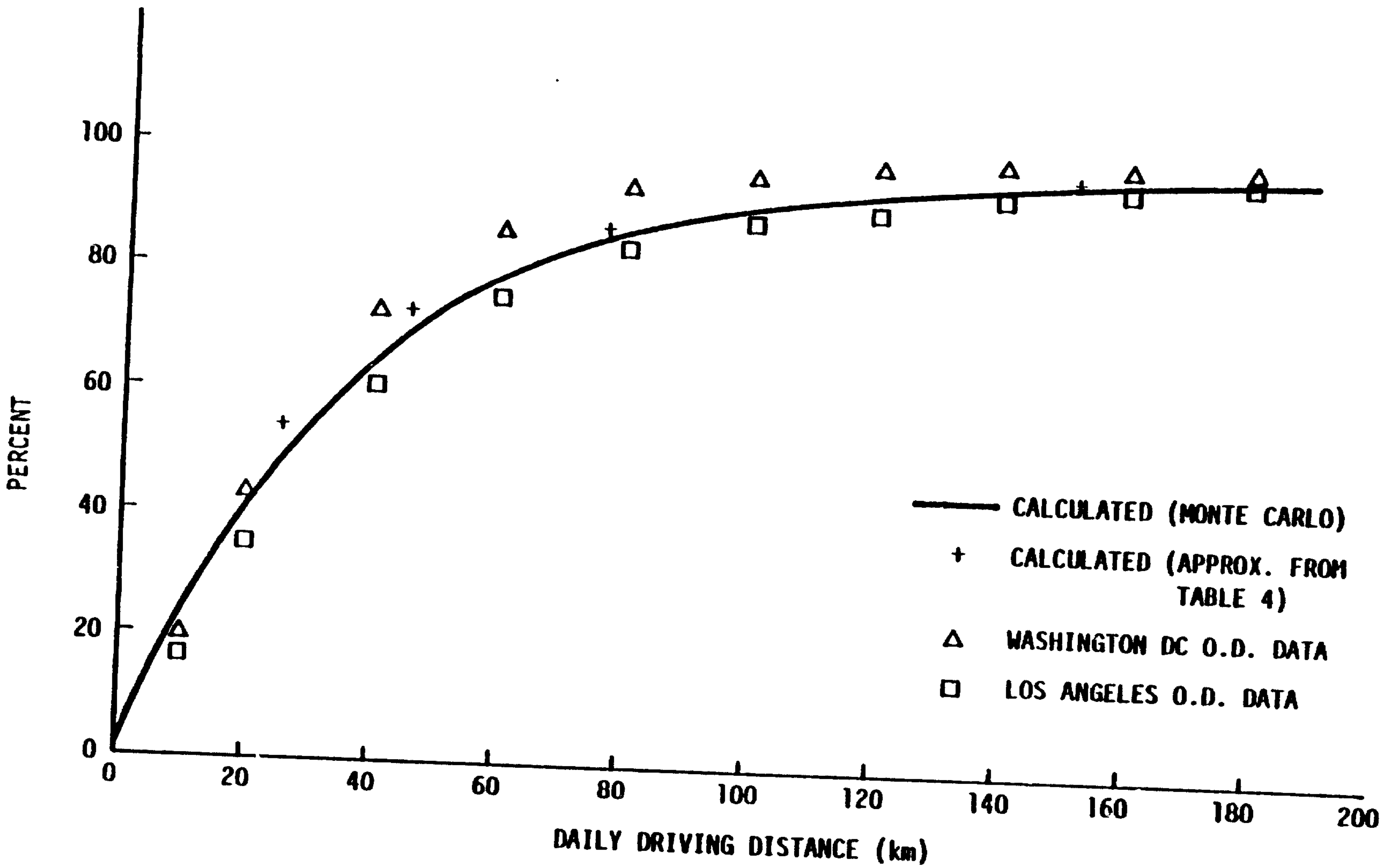

Figure 2. Distribution of Daily Driving Distance

Actual as opposed to calculated daily range distributions were obtained by General Research Corporation* (Volume II) from Washington and Los Angeles origin-destination surveys. These data are also shown in Figure 2. As the figure indicates, GRC results are in reasonable agreement with Schwartz' calculations, although a more detailed analysis, presented in Appendix A, shows that the Poisson assumption is only a very approximate fit to the data. Note that the GRC results do not include trips with destinations outside the metropolitan area. This may account in part for the relatively high proportion of short trips shown by the Washington data.

Unfortunately, there is no data set which breaks down the daily range requirements by mission. Accordingly, such data have to be estimated by a theoretical model, such as that of Volume II of this study. A Monte Carlo routine which combines trip length and trip frequency distributions has been developed earlier by GRC. This is described in Reference 8 and will be used by us as required. Analysis shows, however, that computer results can be estimated with sufficient accuracy by means of empirical approximations. Note that we are approximating computer simulation results which themselves are only approximations to reality. At this stage we conjecture, therefore, that our empirical results are just as good or bad as those of the Monte Carlo simulations. Only further studies will determine if this is in fact so.

Schwartz (Reference 7) used his computer results to derive the formula:

$$R = .0077A + 2.83 \quad , \tag{2}$$

where R is the daily range in miles at the 95th percentile, and A is the average annual travel in miles. This can be rewritten

$$r = 2.8\,\alpha + 4.5 \quad , \tag{3}$$

where α is the average daily range and r is the 95th percentile range, both in kilometers. For some purposes it is instructive to rewrite Equation 3 as

$$r = 2.8\,L\lambda + 4.5 \quad , \tag{4}$$

---

*To the best of our knowledge, these are the first such data available.

where L is the average daily trip length, typically 10 or 20 km, and λ is the mean daily trip frequency, typically three or four trips, when all daily trips are taken into account.

Equation 3 corresponds closely to the rule of thumb we suggested (see Table 2) about trip length distributions — that the 95th percentile is about three times the average. It appears, in fact, that the daily range distribution is similar in form to the trip length distributions shown in Figure 1 and Table 2. As already noted, this form may be approximately characterized as follows:

Percentile	75	90	95	99
Multiple of average value	1	2	3	5

For example, 75 percent of all daily driving is shorter than the average value, and 90 percent is shorter than twice the average. Recall that under Schwartz' assumptions, the average daily driving distance is 45 km and compare with Figure 2.

The above suggests that the daily range distribution can be approximated by multiplying the trip distribution by the mean trip frequency, as shown in Table 4.

Table 4. Estimated Daily Driving Range Distribution (All Trips)

[1] Trip Length Interval (miles) x_1	x_2	[2] λ[1] (λ = 3.14)	P(x)	F(x)	[3] [2]/.62 (km)
0	5	0-15.7	54.1	54.1	25
5	9	15.7-28.2	19.6	73.0	45
10	15	28.2-47	13.8	87.5	76
16	20	47-63	4.3	91.8	102
21	30	63-94	4.0	95.8	152
31	40	94-126	1.6	97.4	203
41	50	126-157	.8	98.2	253
51	99	157-311	1.0	99.2	501

The results of Table 4 are plotted in Figure 2. The agreement with other data encourages us to adopt this simple procedure for the present. As appropriate, Monte Carlo and other computer studies will be made in subsequent sensitivity analyses and trade-off studies to further refine the results of this section.

Having established the necessary methodology, we return to the question of calculating daily driving range requirements for the remaining trip purposes. Toward this end, consider Table 5, which introduces candidate missions.

In Table 5 we took as given the total yearly travel of 19,073 km (from Volume II), the fraction of travel according to trip purpose, and the average trip length (from Reference 4). The remaining numbers were then calculated. For example, 24.2 percent (4635 km) of all travel (19,073 km) is family business. This corresponds to 1.47 trips (12.7 km) per day. The numbers in this table differ slightly from those of previous sections because a different (1985) annual travel distance is assumed.

We have combined Trip Purposes 2 and 3 into Mission C because of the similarity of range and passenger capacity requirements. The implications of Table 5 can be further explained by means of Figure 3. The figure suggests that Mission C definitely deserves consideration because its range requirements appear to be substantially lower than those of general city driving.

At first glance, it appears that Mission C should be combined with Mission D (social and recreational driving) into Mission CD. However, this is deceptive. As Table 5 shows, social and recreational driving occurs relatively infrequently ($\lambda = 0.81$), but, when it does, longer distances ($L = 19.6$) will be involved. From the prospective buyer's point of view, the conditional probability is the crucial number — that is, the conditional probability of driving a longer distance given that a Mission D trip is planned for that day. This distinction will be further discussed in Appendix A.

If anything, Mission D should be combined with Mission B (commuting). However, the requirements for this combined mission are in effect nearly the same as those for Mission A (city driving). Hence BD can be replaced by A. We therefore eliminate the combinations CD and BD from further consideration. Mission B is, however, a worthwhile candidate as a separate mission, for a large portion of the commuter market could be served by a two-passenger car. This is seen in Table 6 (from Reference 4).

Table 5. Daily Driving by Mission
(19,073 km per Vehicle per Year)

Mission	Trip Purpose		Avg. Trip Length (km) (L)	Avg. No. Trips/Day (λ)	Average Distance/Day (Lλ)	Fraction of: Travel	Fraction of: Trips	Travel Per Car Per Year (km)	Daily Range Percentiles Distances (km) 0.75	0.95	0.99
A	1 thru 4	City Driving	13.6	3.74	50.9	96.3	98.8	18,596	51	153	255
B	1	Commute	16.3	1.33	21.7	41.6	36.2	7,934	32	94	160
C	2 and 3	Family & Civic Business	8.65	1.47	12.7	24.2	40.3	4,635	13	38	64
D	4	Social and Recreational*	19.6	0.81	15.9	30.5	22.3	5,817	16	48	80

*Excludes vacation travel.

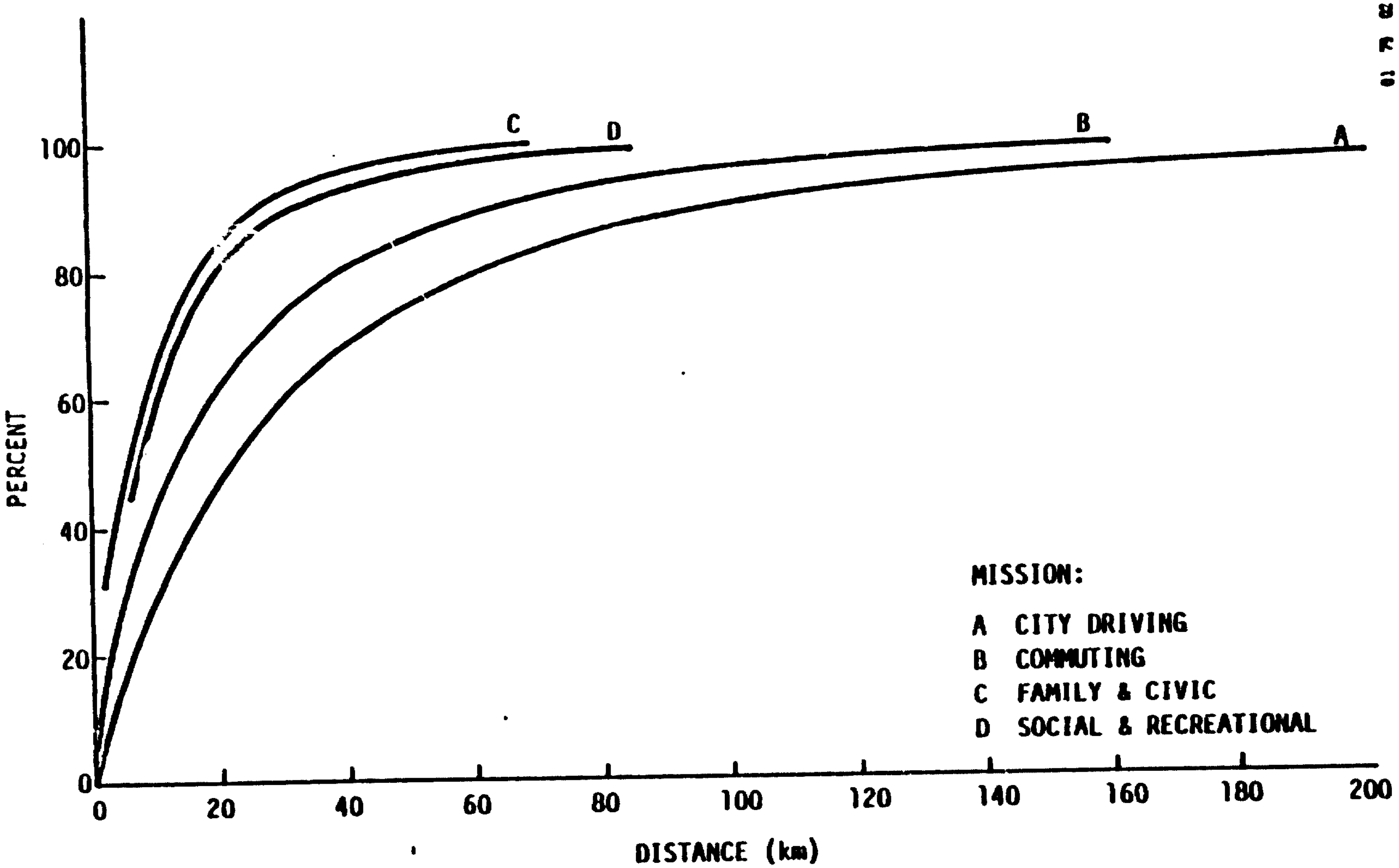

Figure 3. Estimated Distribution of Daily Distance by Mission

Table 6. Distribution of Automobile Occupancy by Trip Purpose (Percentiles)

	Number of Occupants			
Trip Purpose	1	2	3	4
1 Commuting	73.2	18.4	4.5	1.8
2 Family Business	44.4	33.0	12.0	5.4
3 Civic	33.7	26.5	15.8	10.8
4 Soc. & Rec.	50.9	27.3	9.9	5.7

However, it seems unreasonable for the commuter car to be used only to travel back and forth to work. Some allowance must be made, for instance, for shopping, meals and after-work socializing. We therefore assume, in calculating the fuel savings in the next section, that an augmented commute to work mission (call it BB) includes three 10 km (based on the average distance driven in Mission C) lunchtime or after-work trips per week, in addition to the commuting distance.

In summary, we have identified three missions as prime candidates for further study:

Mission		Primary Reason for Selection
A	All-purpose City Driving	Maximum potential market penetration
BB	Commuting	Two-passenger car
C	Family & Civic Business	Minimal range requirements

The optimal HPV for Missions A and C can be designed, subject to all the constraints specified by JPL. The principal difference between the two is that Mission C will have lower range requirements. The optimal HPV for Mission BB does not meet the constraint which specifies a five-passenger vehicle. We include it, nevertheless, so that we have the background information available and so that JPL has the opportunity of evaluating its possible merit.

POTENTIAL PETROLEUM SAVINGS — GENERAL OVERVIEW

It remains to convert driving range requirements to estimates of fuel consumed and potential fuel savings. This will first be done here approximately, under a number of simplifying assumptions, and then more rigorously in the next section, using the commuter mission (BB) as an example. Further detailed analyses will be performed as part of the HPV Trade-off Studies and Sensitivity Analyses later in the HPV program.

In this section we assume that the fuel used is proportional to the distance driven. This assumption is only an approximation. Shorter trips have poorer fuel economy. We also assume that the hybrid vehicle always runs on electricity until its battery reserve limit is reached. Thereafter it runs on the heat engine only. Both of these assumptions are retained not only because they make the calculations much simpler, but also because they are conservative. They underestimate the potential HPV savings. This can be seen by comparing Figure 4 with Figure 9 (page 29).

Given these assumptions, the fraction of fuel saved by the HPV can be immediately estimated from the mission range distribution. Let x_n be the distance of the "longest" trip for a particular purpose, so that $F(x_n) = 1$, where $F(x)$ is the distribution function of daily driving distance. Select a set of intermediate values x_i such that $0 \leq x_i \leq x_n$, $i = 0,1,2,\ldots n$. Then the fraction of all driving done in the electric mode on a given day by a hybrid vehicle of electric range x_m is

$$G(x_m) = \frac{\frac{1}{2}\sum_{i=0}^{m} (x_i + x_{i-1})P(x_i) + x_m\left[1 - F(x_m)\right]}{\frac{1}{2}\sum_{i=0}^{n}(x_i + x_{i-1})P(x_i)} \quad , \qquad (5)$$

where

$$P(x_i) = F(x_i) - F(x_{i-1}) \qquad (6)$$

The approximation, under the stated assumptions, can be made to an arbitrary accuracy by selecting a sufficient number of points x_i. A minor problem arises in that the long and uncertain tails of the range distribution make it difficult to select the "longest" range x_n. This does not contribute a significant error.

The first term of Equation 5 represents the fraction of all travel which electric vehicles of range x_m could drive. Equation 5 was used to calculate the results of Figure 4. The figure shows, for example, that if all Mission C trips were made by hybrid vehicles having a 30 km electric range, only 12 percent of the petroleum now used on this mission would be expended. The corresponding figures for Missions B and A are 35 percent and 50 percent, respectively. As the figure shows, the reduction of petroleum consumption for all city driving (Mission A) to 25 percent of its present value would require a fleet of hybrid vehicles of 65 km electric range or a fleet of all-electric vehicles of 140 km range. Which vehicle is easier to design, build and market? The design, trade-off and cost studies planned for the coming months will help shed some light on this and a host of similar questions.

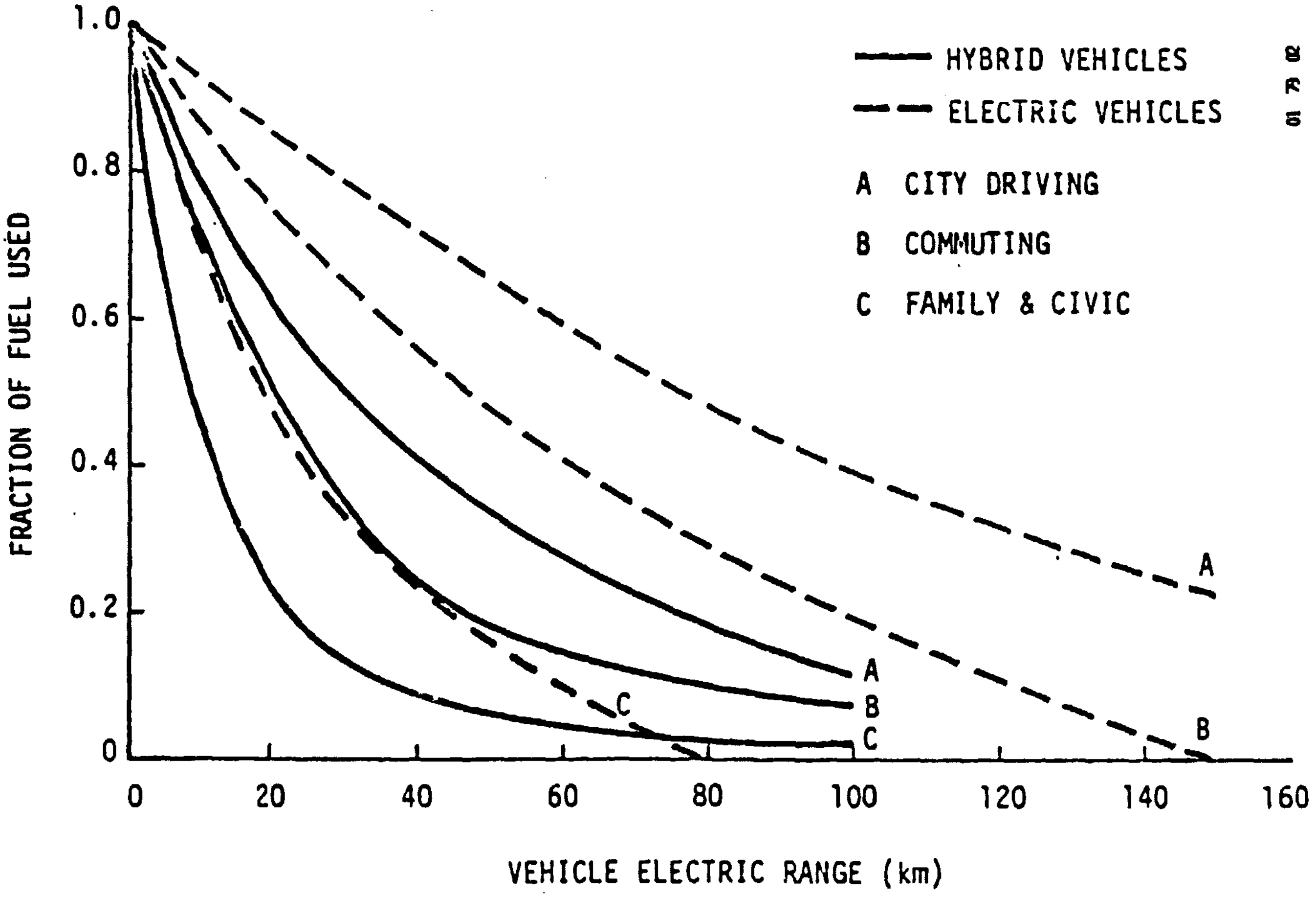

Figure 4. Petroleum Used as a Function of Electric Range

POTENTIAL PETROLEUM SAVINGS — DETAILED
EXAMPLE MISSION BB

In order to calculate potential fuel (petroleum) savings in more detail, we now combine the distribution of trip lengths with the data on expected petroleum economy of the 1985 new vehicle fleet and with the driving cycle combination for the evaluation of petroleum economy. The fuel (petroleum) economy data are contained in Table C-1 of Reference 6, and the driving cycle combination is in Appendix B of this report. Figure 5 is a plot of the expected petroleum consumption of 1985 new cars as a function of trip length. These data are broken down into the five classes used in Reference 6: small, subcompact, compact, full size and large. The data take into account the effects on warm-up of the engine and car on fuel economy and the distribution of types of driving and average speed (Driving Cycles) as a function of trip length as discussed in Appendix B.

The reference vehicle plot is also shown in Figure 5. This vehicle represents the class of vehicles that the proposed hybrid will be able to replace. The reference vehicle is an average of the compact and full size cars. This class was selected primarily on the basis of size. Since the proposed hybrid will be a five-passenger car, it will be too small to fulfill the requirements of a six-passenger vehicle, and it will also be much larger and heavier than a small or subcompact car. The reference vehicle will be used as one standard of comparison in assessing the petroleum savings of the hybrid.

Figure 6 is a re-plot of the data in Figure 5, showing the relative fuel economies as a function of trip length and the variations of relative economy with vehicle size. The relative economy 1.0 on the vertical scale is the Federal Highway Driving Cycle Fuel Economy for the particular size vehicle. The highway economies are 11.2 km per liter for the large vehicle, 20.2 km per liter for the small vehicle, and 14.3 km per liter for the reference vehicle. This plot shows that, over a wide range of trip lengths, particularly trips between 5 and 40 km, there are differences in the warm-up rates of small and large cars. Again the reference vehicle falls in the middle of the spread.

The data in both Figures 5 and 6 are shown for a 20°C ambient temperature. Other temperatures would change these numbers

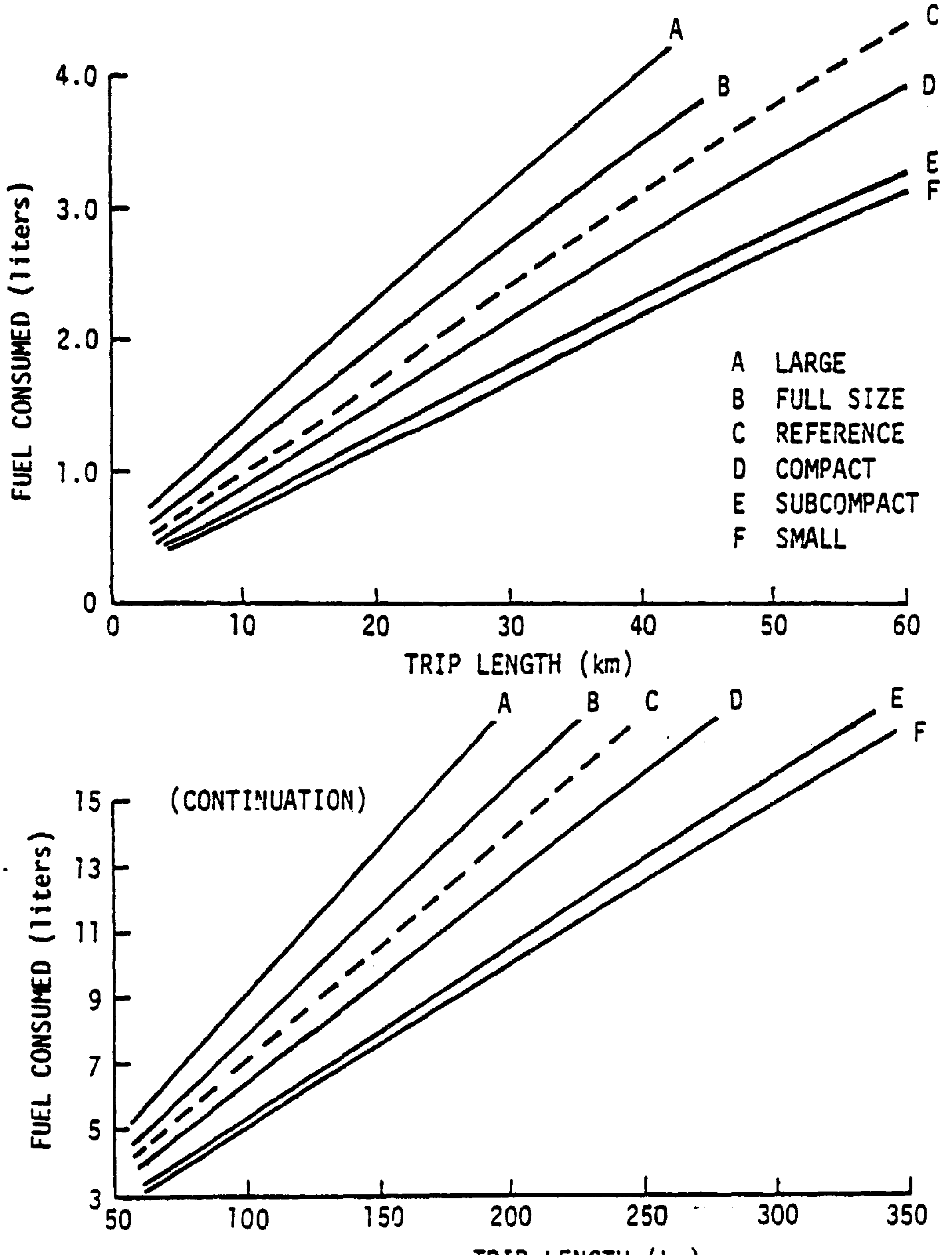

Figure 5. Fuel (Petroleum) Economy -
1985 New Cars

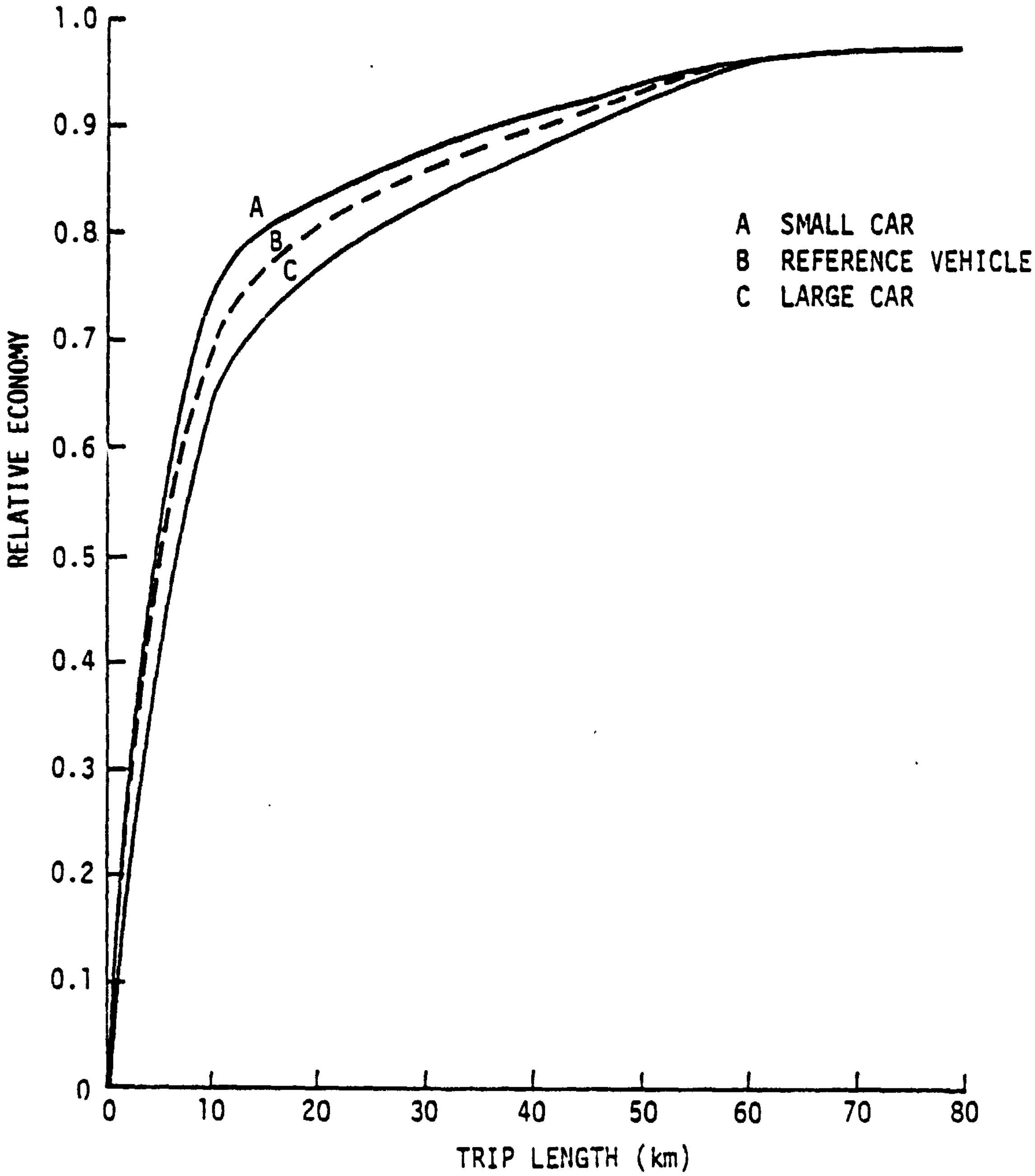

Figure 6. Relative Fuel (Petroleum) Economy - Effect of Short Trips

because of the effects of warm-up, but these data serve to illustrate the overall effects of petroleum consumption as a function of trip length and vehicle size. The effect of ambient temperature is discussed in detail in Appendix B and will be further examined in the forthcoming Sensitivity Analyses and Trade-off Studies.

Table 7 takes the petroleum consumption data from Figure 5 and combines it with the trip length distribution from Table 2 to give us the consumption of petroleum for each size car for each decile of trip length for a Mission BB use. In the last column of the table the data for the individual vehicle sizes are combined and weighted by the expected composition of the 1985 new vehicle fleet (from Reference 6) to give values for the combined 1985 new vehicle fleet. We now are in a position to calculate the expected value of petroleum economy for any of the car types shown in Table 7.

We next calculate a similar set of results for hybrid vehicles. Figure 7 shows the fuel usage of a proposed hybrid vehicle as a function of the distance traveled since the last battery charge. These preliminary calculations cover electric ranges between 10 and 40 km. In order to gain this data, we assumed that the hybrid runs in an all-electric mode until the battery reserve limit is reached, and thereafter operates on all-heat engine power. The particular vehicle shown here has a 50 kW turbocharged diesel engine and a 22 kW electric motor with varying battery capacities to give the different ranges. The loaded vehicle weights vary between 1600 and 1900 kg for the various battery capacities.

The data in Figure 7 show that not only is there a reduction in petroleum usage with longer electric range for the hybrid vehicle, but also there is a lower rate of petroleum usage by the hybrid vehicle when the diesel engine is in use (compared to the petroleum consumption of the reference vehicle). This is a result of the outstanding petroleum economy of the turbocharged diesel engine, which, if run at the same weight as the reference vehicle (without the weight of the batteries and motor of the hybrid vehicle), would use about 60 percent as much petroleum as the gasoline engine reference vehicle. However, such a vehicle would not have the acceleration potential either of the reference vehicle or of the hybrid, which can use both diesel and electric power for maximum acceleration.

Table 7. 1985 Distribution of Fuel Economy — Commuter Trips

Decile (x)	Interval (km)	F(x)	P(x)	Avg Trip Length (km)	Fuel Per Trip (Liters) Small	Sub-Compact	Compact	Reference	Full Size	Large	1985 New Car Fleet Mix
0-.1	0-4.5	.6	.60	2.25	.33	.37	.43	.49	.57	.69	.51
.1-.2	4.5-9.0	.76	.16	6.75	.53	.58	.68	.77	.90	1.08	.80
.2-.3	9.0-13.5	.84	.08	11.25	.74	.80	.96	1.07	1.26	1.50	1.12
.3-.4	13.5-18.0	.90	.06	15.75	.97	1.04	1.25	1.38	1.63	1.93	1.46
.4-.5	18.0-22.5	.93	.03	20.25	1.20	1.28	1.54	1.73	1.98	2.35	1.78
.5-.6	22.5-27.0	.95	.02	24.75	1.42	1.52	1.83	2.05	2.33	2.74	2.10
.6-.99	27.0-45.0	.99	.04	36.00	1.98	2.11	2.52	2.83	3.16	3.69	2.86
				10.00	.67	.73	.88	.99	1.15	1.36	1.03

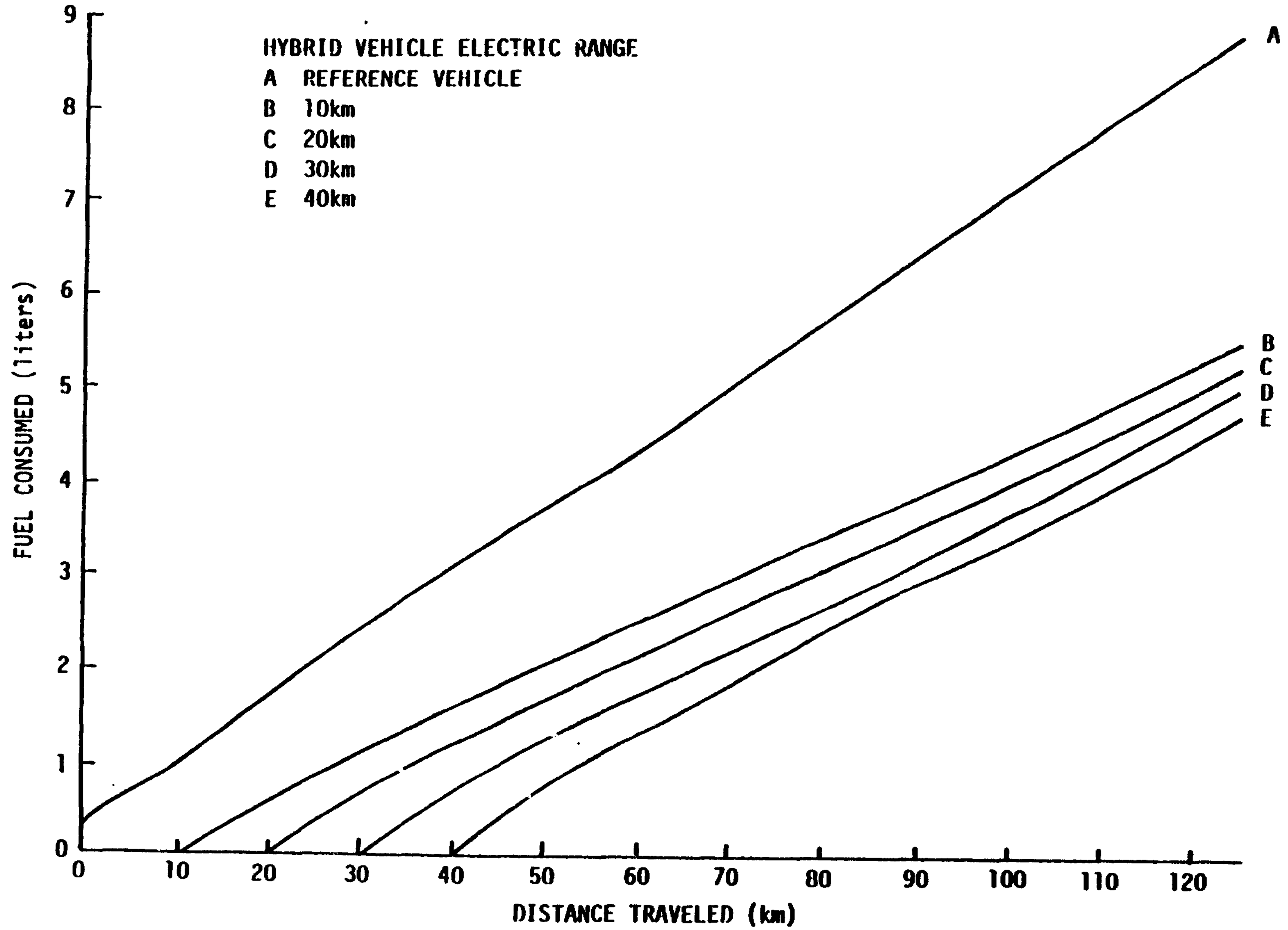

Figure 7. Hybrid Vehicle Fuel (Petroleum) Consumption

Figure 8 shows the same data as Figure 7, but replotted to show petroleum savings for the hybrid for the electric ranges of 10, 20, 30 and 40 km. As in all of the cases discussed here, both conventional and hybrid, the driving cycle combinations described in Appendix B are used to evaluate petroleum and electric energy consumption. Figure 7 shows that, despite the extra battery weight, the longer all-electric range will yield greater petroleum savings to distances far beyond the 125 km shown on the graph. (At a distance of about 200 km the petroleum consumption of all four hybrid vehicles will essentially be equal.)

Table 8 combines the petroleum consumption of the reference vehicle from Figure 5 and Table 7 with the petroleum consumption of the hybrid vehicle with different all-electric ranges from Figure 7 into weekly petroleum usage for Mission BB. In addition to the home-to-work distance traveled twice a day, we also assume three 10 km lunch time and shopping trips per week. To find the total petroleum usage for the reference vehicle, it is only necessary to add the petroleum consumed in ten home-to-work trips and three 10 km trips. For the hybrid, petroleum consumption is determined by the daily distance traveled between battery recharges. We have assumed that on two days a week the vehicle travels twice the home-to-work distance of the particular decile, and on the other three days it travels twice the home-to-work distance plus 10 km. For each of the average trip length deciles Table 8 shows the petroleum consumed by the reference vehicle, the 1985 weighted new vehicle fleet, and the hybrid with 10, 20, 30 and 40 km all-electric ranges. When the data on weekly petroleum consumption for the 1985 new car fleet are compared to the hybrid petroleum consumption and the result is weighted for the distribution of different trip lengths, we obtain the plot shown in Figure 9. This plot gives us the fraction of petroleum used by the hybrid vehicle with different all-electric ranges compared to the petroleum used by the average of the 1985 new vehicle fleet, when both are engaged in Mission BB use. Figure 9, therefore, tells us the savings for each car in the 1985 fleet which is replaced by an HPV. These results must now be scaled by the number of cars engaged in the mission in order to obtain the total fuel savings.

We plan to make similar calculations for Missions A and C (see the previous section) and thus, with the aid of the Sensitivity Analyses and Trade-off Studies, to identify the "optimal" combination of vehicle and mission.

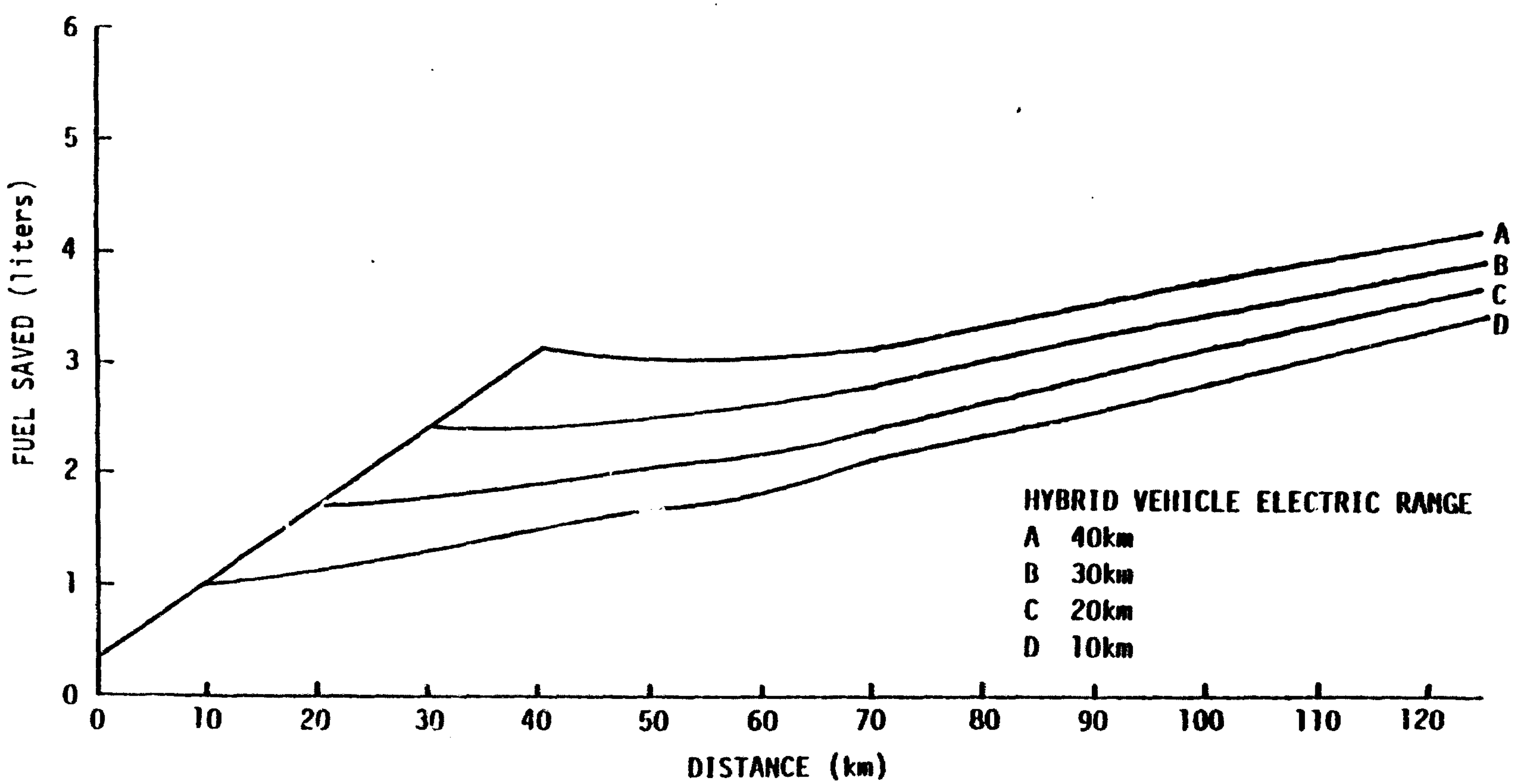

Figure 8. HPV Fuel (Petroleum) Savings Relative to Reference Vehicle

Table 8. Weekly Fuel Consumption — Commuter Trips

Daily Range (km)		Average Trip Length (km)	Fuel Per Trip (Liters)		Fuel Consumed Per Week (Liters)					
							HV with Elect Range of			
Max	Min		1985 New Car Fleet	Reference Vehicle	1985 New Car Fleet	Reference Vehicle	10 km	20 km	30 km	40 km
14.5	4.5	2.25	.51	.49	8.2	7.9	0.9	0.0	0.0	0.0
23.5	13.5	6.75	.80	.77	11.1	10.7	2.8	0.8	0.0	0.0
32.5	22.5	11.25	1.12	1.07	14.3	13.7	5.2	3.2	1.2	0.0
41.5	31.5	15.75	1.46	1.38	17.7	16.8	6.4	5.4	2.7	0.4
50.5	40.5	20.25	1.78	1.73	20.9	20.3	9.6	7.6	5.4	2.5
59.5	49.5	24.75	2.10	2.05	24.1	23.5	11.6	9.8	7.7	5.4
82	72.0	36.00	2.86	2.83	31.7	31.3	16.7	14.9	13.1	11.8
		10.00	1.03	.99						

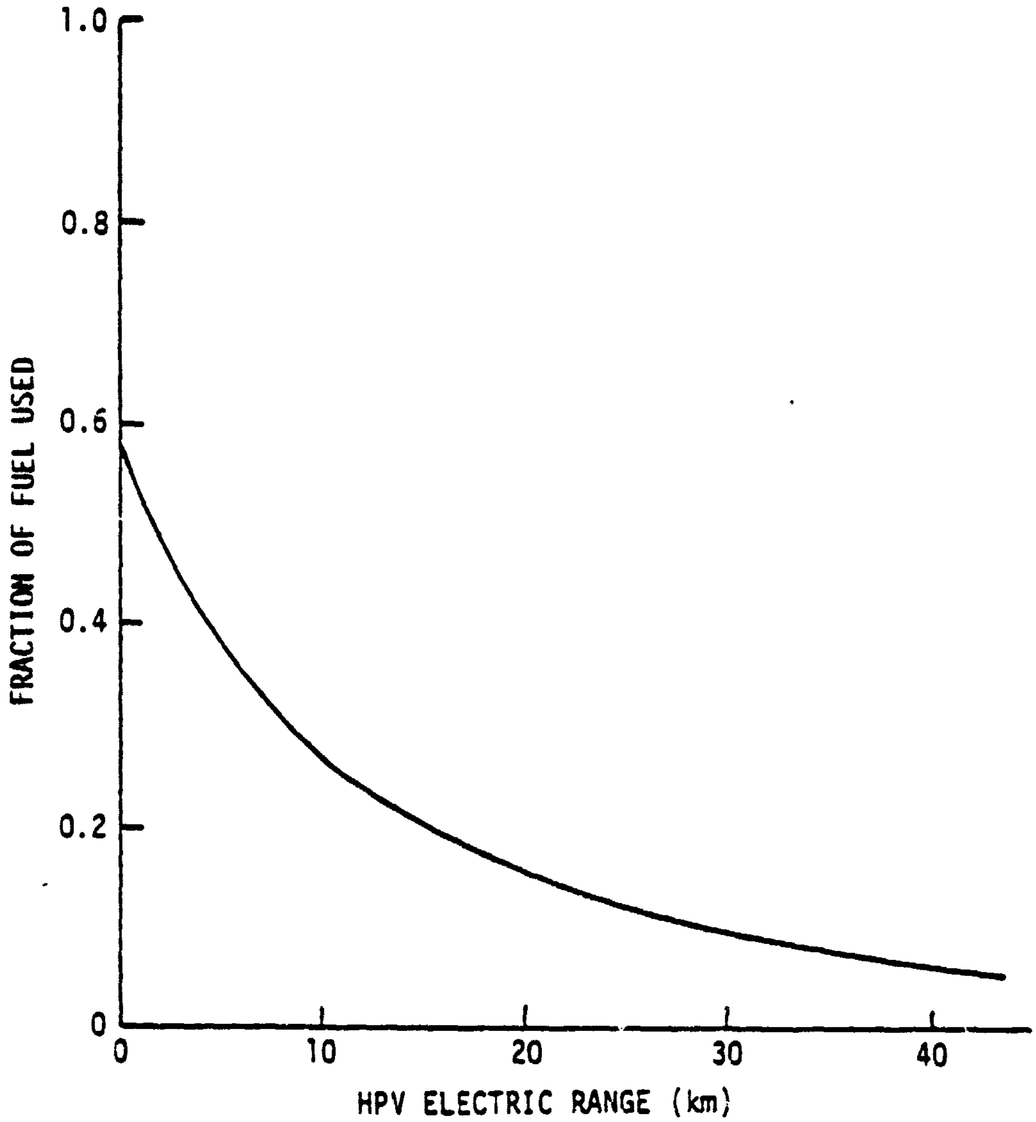

Figure 9. Fuel (Petroleum) Used by Hybrid Vehicle As A Fraction of That Used by An Average 1985 New Vehicle — Mission BB

VEHICLE PERFORMANCE SPECIFICATIONS

P1	Minimum Non-Refueled Range				
	P1.1	FHDC			500 km
	P1.2	FUDC			385 km
	P1.3	J227a(B)			350 km
P2	Cruise Speed				110 km/h
P3	Maximum Speed				
	P3.1	Maximum speed			170 km/h
	P3.2	Length of time maximum speed can be maintained on level road			5 min.
P4	Accelerations				
	P4.1	0-50 km/h (0-30 mph)			6.0 sec
	P4.2	0-90 km/h (0-56 mph)			15.0 sec
	P4.3	40-90 km/h (25-56 mph)			12.0 sec
P5	Gradeability				
			Grade	Speed	Distance
	P5.1		3%	90 km/h	1.0 km
	P5.2		5%	80 km/h	1.0 km
	P5.3		8%	50 km/h	0.3 km
	P5.4		15%	25 km/h	0.2 km
	P5.5		40+%	30 km/h	0.2 km
P6	Payload Capacity				430 kg
P7	Cargo Capacity				0.5 m^3
P8	Consumer Costs				
	P8.1	Consumer purchase price (1977 $)			Competitive $
	P8.2	Consumer life cycle cost (1977 $)			Less than or equal to reference vehicle

P9	Emissions - Federal Test Procedure		
	P9.1	Hydrocarbons (HC)	<0.24 gm/km
	P9.2	Carbon monoxide (C)	< 4.4 gm/km
	P9.3	Nitrogen oxides (NO_x)	<0.93 gm/km
P10	Ambient Temperature Capability		
		Temperature range over which minimum performance requirements can be met	-20°C to +40°C
P11	Rechargeability		
		Maximum time to recharge from 80% depth-of-discharge	8 hr
P12	Required Maintenance		
		Routine maintenance required per month	2 hr
P13	Unserviced Storeability		
		Unserviced storage over ambient temperature range of -30°C to +50°C (-22°F to +122°F)	
	P13.1	Duration	30 days
	P13.2	Warm-up time required	5 min.
P14	Reliability		
	P14.1	Mean usage between failures - powertrain	20,000 km
	P14.2	Mean usage between failures - brakes	20,000 km
	P14.3	Mean usage between failures - vehicle	20,000 km
P15	Maintainability		
	P15.1	Time to repair - mean	12 hr
	P15.2	Time to repair - variance	$^{+20}_{-6}$ hr

P16 Availability

Minimum expected utilization rate, i.e., 100 × time in service ÷ (time in service + time under repair) 90%

P17 Additional Accessories and Amenities

Power steering

Power brakes

Heater/air conditioner

Computer controlled transmission

State of charge meter

Battery charger

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APPENDIX A

FURTHER ANALYSIS OF LOS ANGELES AND WASHINGTON, D.C. ORIGIN-DESTINATION DATA

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FURTHER ANALYSIS OF LOS ANGELES AND WASHINGTON, D.C. ORIGIN-DESTINATION DATA

Data collected in Los Angeles and Washington, D.C. origin-destination studies have been analyzed by General Research Corporation (Volume II of the present study). We examined these data in order to obtain a further characterization of automobile usage. A fundamental result of this examination is that the Poisson probability distribution provides a relatively poor fit to trip frequency data. Attempts to fit the Poisson to actual data are described below; a model which may more effectively predict trip frequency is also discussed.

Driving characteristics in Washington and Los Angeles clearly differ. Therefore, each locale should be modeled separately. The mean number of vehicle trips per day in Washington is 3.16, and the mean distance traveled over the course of a day is 35 km. In contrast, the corresponding figures for Los Angeles are 4.72 trips and 46 km. These observed results are in general agreement with those calculated from Federal Highway Administration data.[1]

The Poisson distribution has been used in the past to model trip frequency. This distribution (commonly applied to waiting line and queuing problems, such as the number of cars at an intersection) may be thought of as a "rare event" distribution, because it is used to model the number of occurrences of an event in a large number of trials when the event's probability at each trial is small. Situations for which the Poisson is excellent include modeling radioactive emissions and transistor failures. The Poisson, which is a discrete rather than a continuous distribution, is completely described by λ, the mean number of events per unit time. A list of the Poisson probabilities of k events for λ equal to the integers 1 through 5 is contained in Table A-1.

Figure A-1 is a histogram showing observed trip frequencies in Washington, D.C. As one might expect, an odd number of trips in a day occurs much less frequently than an even number. The resulting irregularity in the distribution makes it difficult to fit simple parametric models, such as a Poisson distribution. Therefore, if any comparison to a parametric model is to be effective, the data must be represented so as to remove the odd/even characteristic.

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[1] U.S. Department of Transportation, "Nationwide Personal Transportation Survey," 1972.

Table A-1. The Poisson Distribution: P(k) for λ = 1, 2, 3, 4 and 5 (in percent)

k	$\lambda = 1$	$\lambda = 2$	$\lambda = 3$	$\lambda = 4$	$\lambda = 5$
0	37	14	5	2	1
1	37	27	15	7	3
2	18	27	22	15	8
3	6	18	22	20	14
4	2	9	17	20	18
5	0	4	10	16	18
6	0	1	5	10	15
7	0	0	2	6	10
8	0	0	1	3	7
9	0	0	0	1	4
10	0	0	0	1	2
11	0	0	0	0	1

$$P(k) = \frac{\lambda^k}{k!} e^{-\lambda}$$

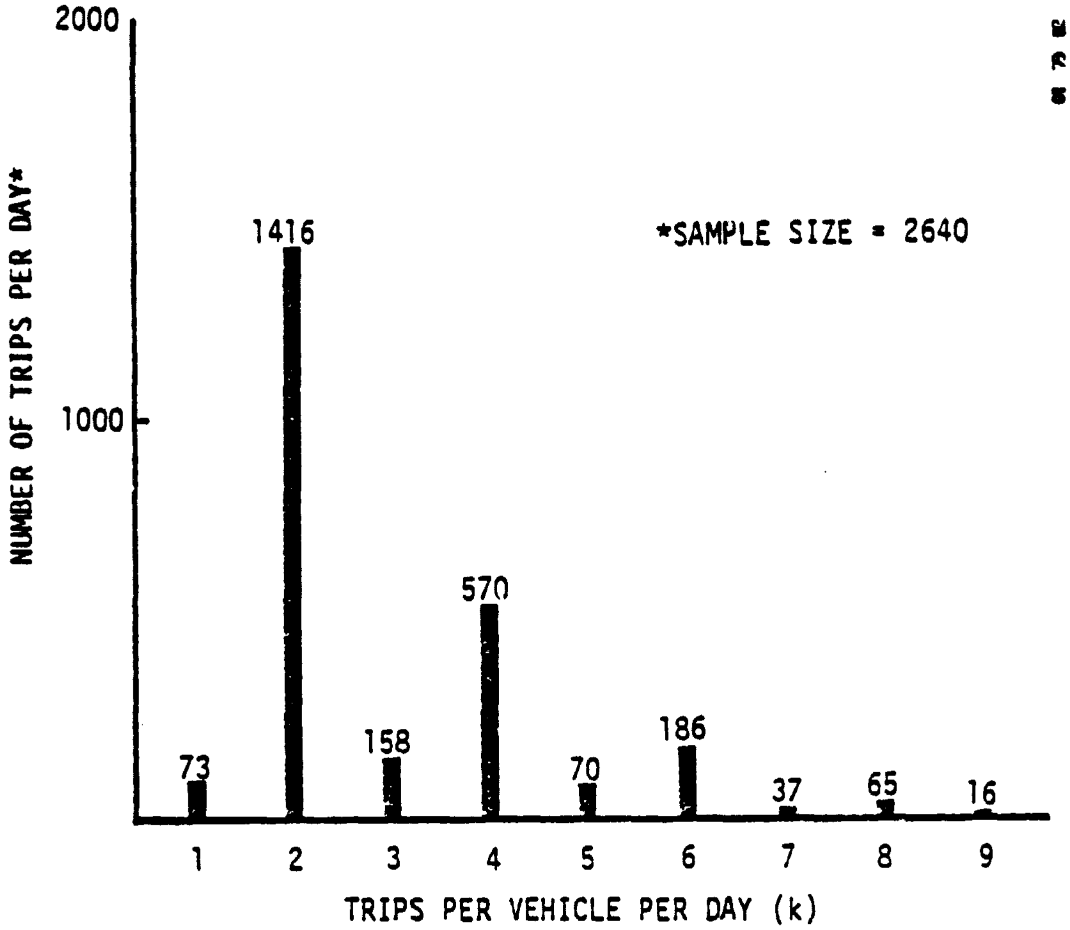

Figure A-1. Numbers of Trips Daily — Washington, D.C. Sample

Odd and even numbers of trips have been combined in Figure A-2. The frequency of zero trips and the frequency of one trip are summed to form the frequency of zero <u>or</u> one trip (per day); the frequency of two trips and the frequency of three trips are summed to form the frequency of two <u>or</u> three trips, and so on. The histogram of Figure A-2 is smooth and illustrates the distribution's overall skew-positive shape.

The Poisson distribution is fitted to data by estimating λ, the distribution's only parameter. The maximum likelihood estimator of λ is the sample mean given by

$$\hat{\lambda} = \frac{0N_0 + 1N_1 + 2N_2 + \ldots + nN_n}{\sum_0^n N_i} , \qquad \text{(A-1)}$$

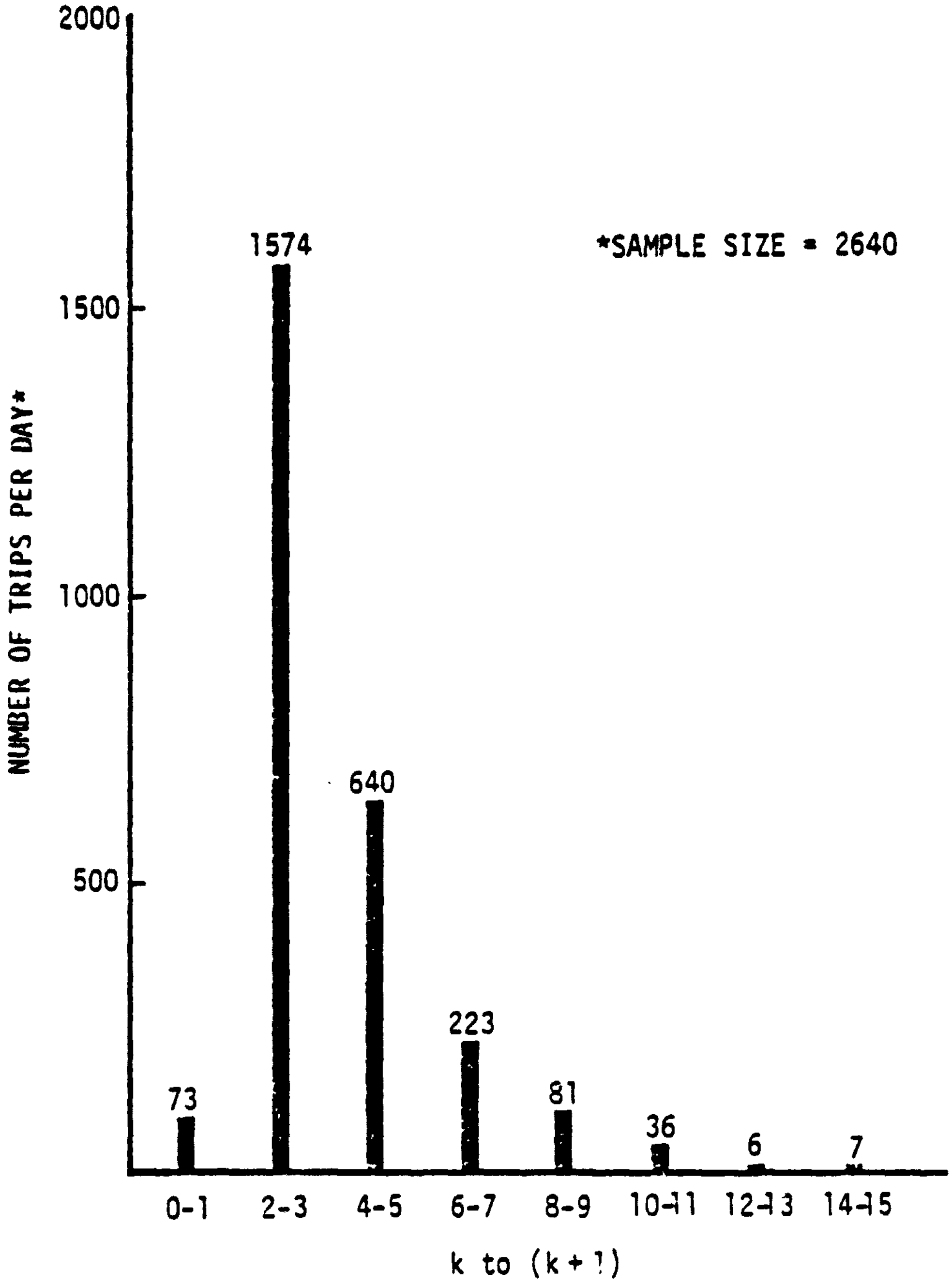

Figure A-2. Number of Trips Daily in Two-Trip Bins - Washington, D.C. Sample where N_i is the observed number of occurrences of i trips. Unfortunately, the GRC data do not include N_0 which is needed to calculate $\sum_{i=0}^{n} N_i$. The result of substituting a value of zero for N_0 is that the sample mean will tend to be larger than λ. Since an optimal estimator for λ is not directly available, a spectrum of Poisson distributions were fitted to data. The values of λ were set less than or equal to the sample mean from Equation A-1, computed with N_0 equal to zero. The nature of the Poisson fit was examined as λ varied.

Figures A-3 and A-4 compare the values predicted by two Poisson distributions and the observed Washington trip frequencies. The Poisson fit of Figure A-3 was constructed with λ set at the sample mean of 3.16. The model underestimates the frequency of two or three trips. The fit of Figure A-4 was obtained with λ set to 2.88. A smaller λ improves the model's prediction of two or three trips, but degrades the fit in the distribution's tail or extreme values. For example, while 36 occurrences of 10 or 11 trips are recorded in the Washington data, only two are predicted by the Poisson distribution. A poorer fit occurs using the Los Angeles data, as is shown in Figure A-5. In this case, the Poisson model is hardly satisfactory.*

The Poisson distribution fails to fit the Washington and Los Angeles data primarily because the observed distribution's central portion is large relative to its tail. The frequency of two trips is particularly high, suggesting a systematic bias toward this number of trips. Such a systematic bias is best explained as an effect of work-related trips.

We shall outline here a somewhat complex model of trip frequency which takes into account the apparently substantial effect of work trips. The population of car owners is divided into two categories, those who drive to work and those who do not. The week is then divided into weekdays and weekends. Driving behavior in each category is characterized, and the sum of the driving behaviors, weighted according to relative probabilities, forms the overall distribution of trip frequency.

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*While the Poisson model does a relatively poor job of predicting trip frequencies, it, in combination with observed trip length distributions, appears to be reasonably accurate in deriving daily driving distances. (See the main text of this study.)

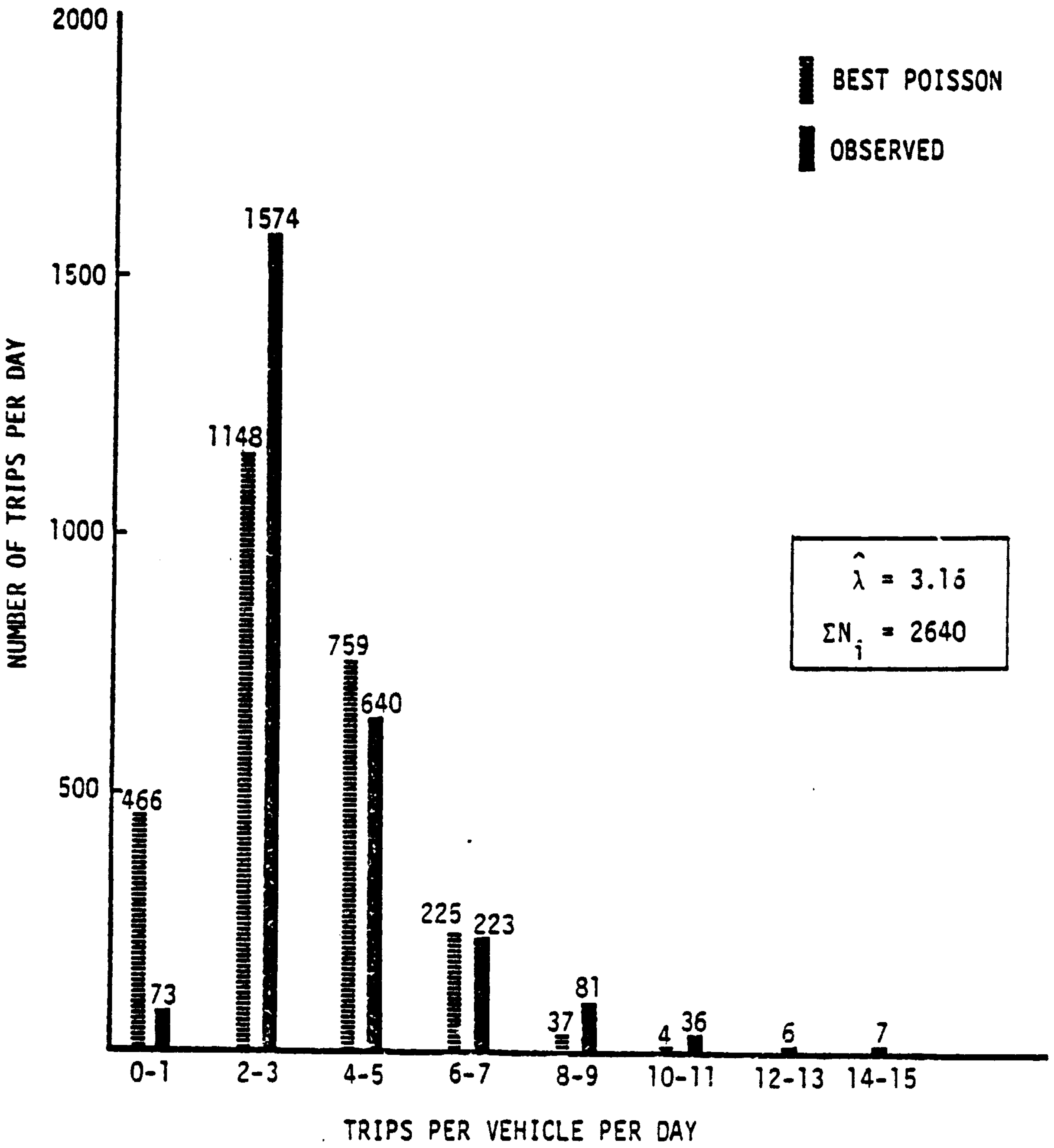

Figure A-3. A Comparison of Washington Daily Trips and Poisson Distribution Predictions

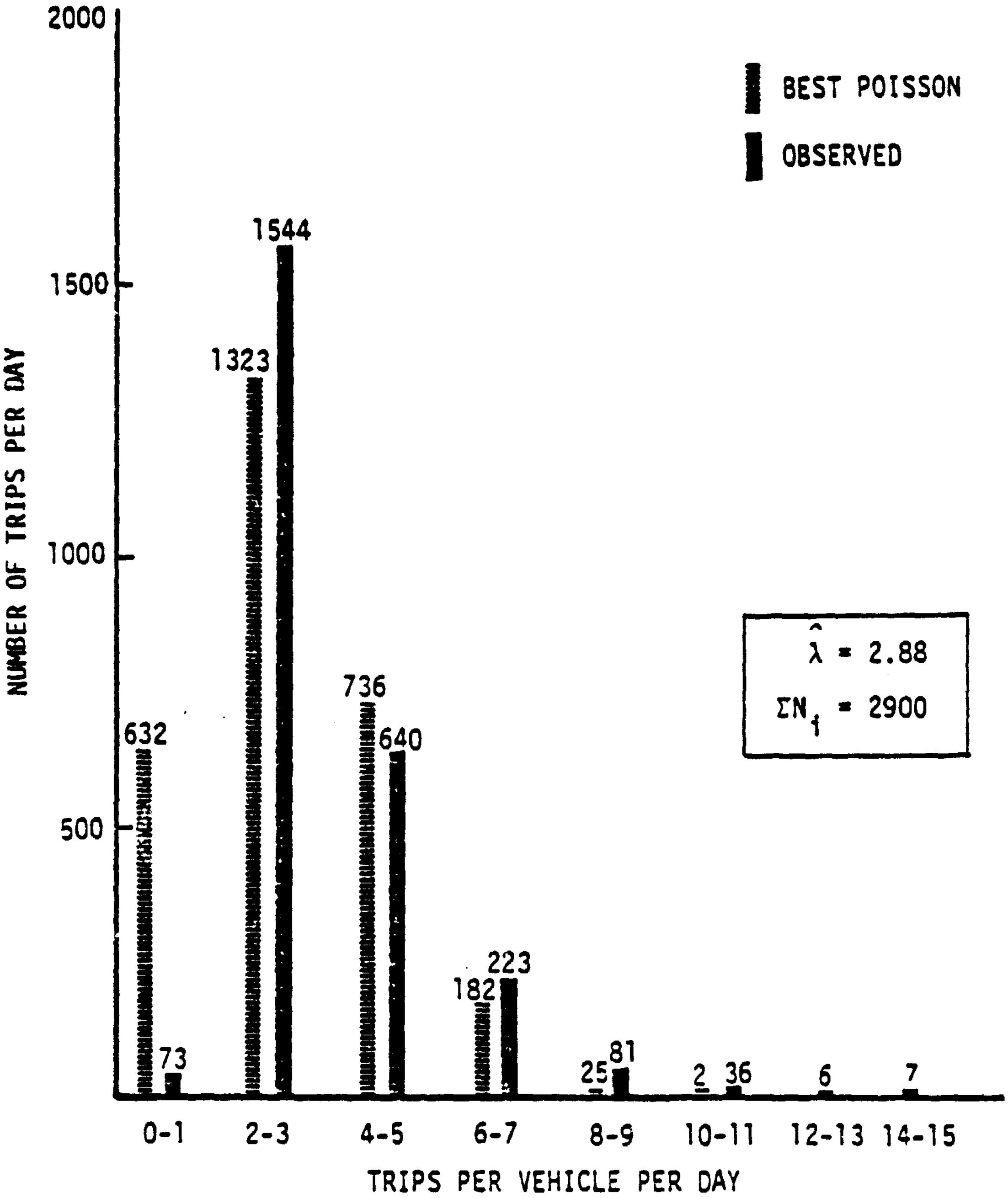

Figure A-4. A Comparison of Washington Daily Trips and Poisson Distribution Predictions with Adjusted λ

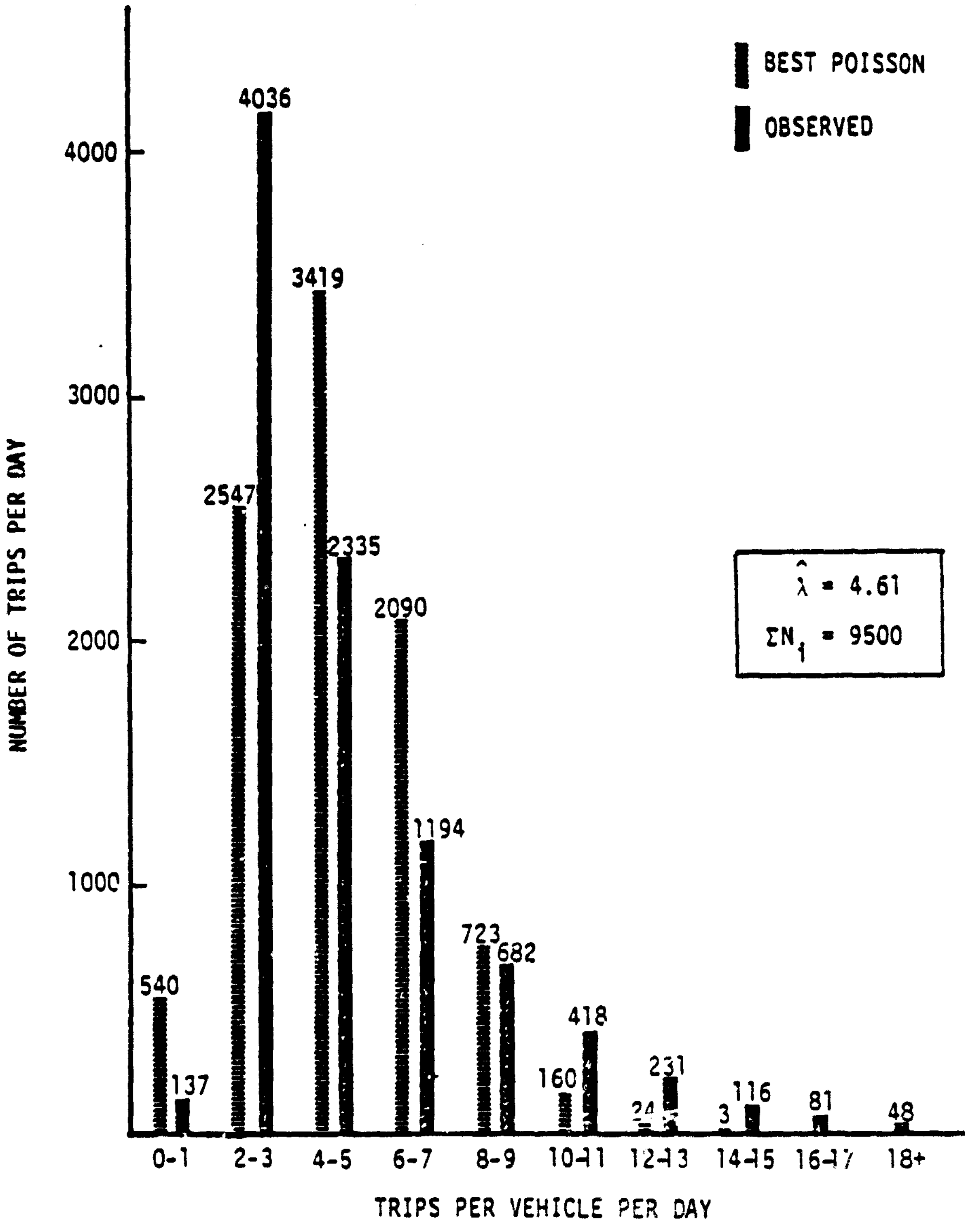

Figure A-5. A Comparison of Los Angeles Daily Trips and Best Poisson Predictions

Let N_1 and N_2 represent the number of car owners who drive to work and do not drive to work, respectively. Then a randomly selected driver has probability $N_1/(N_1 + N_2)$ of being a driver who drives to work, and probability $N_2/(N_1 + N_2)$ of being a driver who does not. A randomly selected day has probability 2/7 of being a weekend day and 5/7 of being a weekday. The four categories that will be conditioned on and their relative probabilities are, then,

Category Label	Description	Probability
A	Person drives to work and it is a weekday	$\frac{N_1}{N_1 + N_2}\left(\frac{5}{7}\right)$
B	Person drives to work and it is a weekend day	$\frac{N_1}{N_1 + N_2}\left(\frac{2}{7}\right)$
C	Person does not drive to work and it is a weekday	$\frac{N_2}{N_1 + N_2}\left(\frac{5}{7}\right)$
D	Person does not drive to work and it is a weekend day	$\frac{N_2}{N_1 + N_2}\left(\frac{2}{7}\right)$

The objective here is to find the probability of k trips in a day, for k varying from zero to infinity. Let this probability be denoted by P(k). Then,

$$P(k) = P(k/A)P(A) + P(k/B)P(B) + P(k/C)P(C) + P(k/D)P(D) \quad . \tag{A-2}$$

The expression P(k/A) should be read as "the probability of k trips occurring given that situation A is known to be true." The probabilities of A, B, C and D are shown in the table above. The remaining task here is to derive the set of conditional probabilities of k given A, B, C and D.

The values of P(k/A) result from two basic assumptions: first, a person who drives to work takes <u>at least</u> two trips on a weekday; second, this person may take additional discretionary trips on a weekday, and the mean number of such trips is λ_1. Assume further that the discretionary trips follow a Poisson distribution. The result is

$$P(0/A) = 0$$

$$P(1/A) = 0 \quad ,$$

since Category A implies at least two trips. In addition,

$$P(2/A) = P(2 \text{ work trips})P(0 \text{ discretionary trips})$$

$$= 1 \times \frac{\lambda_1^{0}}{0!} \exp(-\lambda_1)$$

$$= \exp(-\lambda_1)$$

$$P(3/A) = P(2 \text{ work trips})P(1 \text{ discretionary trip})$$

$$= 1 \times \frac{\lambda_1^{1}}{1!} \exp(-\lambda_1)$$

$$= \lambda_1 \exp(-\lambda_1) \quad ,$$

and so on. The general solution may be written

$$P(k/A) = \begin{cases} 0 \quad , & k < 2 \\ \dfrac{\lambda_1^{(k-2)}}{(k-2)!} \exp(-\lambda_1) \quad , & k \geq 2 \end{cases} \quad .$$

The probability of k trips is assumed to be identical for conditions B, C and D. These probabilities are assumed to follow a Poisson distribution with parameter λ_2, where λ_2 is the mean number of discretionary trips taken by a driver on a day he does not work. As such, the probability of k given B, C or D may be written

$$P(k/B, C \text{ or } D) = \frac{\lambda_2^{k}}{k!} \exp(-\lambda_2) \quad .$$

Substitution into Equation A-2 yields

$$P(k) = (0)\left(\frac{N_1}{N_1 + N_2}\right)\left(\frac{5}{7}\right) + \left[\frac{\lambda_2^{\,k}}{k!}\exp(-\lambda_2)\right]\left[1 - \left(\frac{N_1}{N_1 + N_2}\right)\left(\frac{5}{7}\right)\right]$$

for k less than 2, and

$$P(k) = \left[\frac{\lambda_1^{\,(k-2)}}{(k-2)!}\exp(-\lambda_1)\right]\left(\frac{N_1}{N_1 + N_2}\right)\left(\frac{5}{7}\right)$$

$$+ \left[\frac{\lambda_2^{\,k}}{k!}\exp(-\lambda_2)\right]\left[1 - \left(\frac{N_1}{N_1 + N_2}\right)\left(\frac{5}{7}\right)\right]$$

for k greater than or equal to 2.

This model will be further investigated to see how well it accounts for the observed trip frequency distributions.

APPENDIX B

DRIVING CYCLES AND AUTOMOTIVE FUEL ECONOMY

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DRIVING CYCLES AND AUTOMOTIVE FUEL ECONOMY

B.1 SPECIFYING THE J227a(B) CYCLE

In the effort reported below, the objective was to establish a realistic J227a(B) cycle, so as to be representative of the way we would expect a hybrid vehicle to be driven. This driving cycle (primarily based on a priori considerations) may then be used in the CARSIM model, in conjunction with the Federal Urban and Highway driving cycles, to establish the petroleum consumption, as a function of trip length and other parameters, for both the reference ICE vehicle and the NTHV. It is expected that the cycle will change slightly as the characteristics of these vehicles become better defined.

The J227a(B) cycle is described in terms of a velocity-time profile, which is usually expressed as shown in Figure B-1. However, the velocity is prescribed in this cycle only during the cruise portion and at the end points of the acceleration, cruise and deceleration periods. The remainder of the profile is not prescribed. In fact, since part of the deceleration portion involves coast-down, the actual profile will depend not only on driving behavior, but on the specific nature of the vehicle. In the sections that follow, the velocity-time profile for each portion of the J227a(B) cycle will be derived.

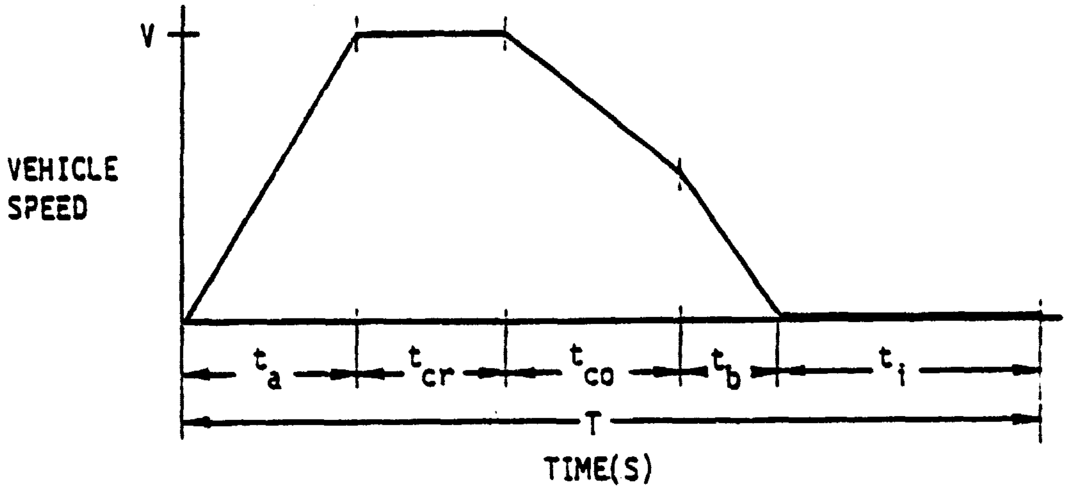
B.1.1 Acceleration Phase

The acceleration phase was divided into four segments, as indicated in Figure B-2, and the thinking behind much of this stems from the basic expression for power P at the driving wheels:

$$P = V(C_0 + C_1V + C_2V^2 + C_3 \frac{dV}{dt}) \quad , \qquad \text{(B-1)}$$

in which

P = power at the driving wheels
V = velocity
t = time
C_i = positive constraint that depends on vehicle and drive-line characteristics.



Schedule	A	B	C	D
V	16 ± 1.5 km/h (10 ± 1 mph)	32 ± 1.5 km/h (20 ± 1 mph)	48 ± 1.5 km/h (30 ± 1 mph)	72 ± 1.5 km/h (45 ± 1 mph)
t_a	4 ± 1	19 ± 1	18 ± 2	28 ± 2
t_{cr}	0	19 ± 1	20 ± 1	50 ± 2
t_{co}	2 ± 1	4 ± 1	8 ± 1	10 ± 1
t_b	3 ± 1	5 ± 1	9 ± 1	9 ± 1
t_i	30 ± 2	25 ± 2	25 ± 2	25 ± 2
T	39 ± 2	72 ± 2	80 ± 2	122 ± 2

NOTE: All times shown are in seconds.

Figure B-1. SAE J227a(B) Test Cycles

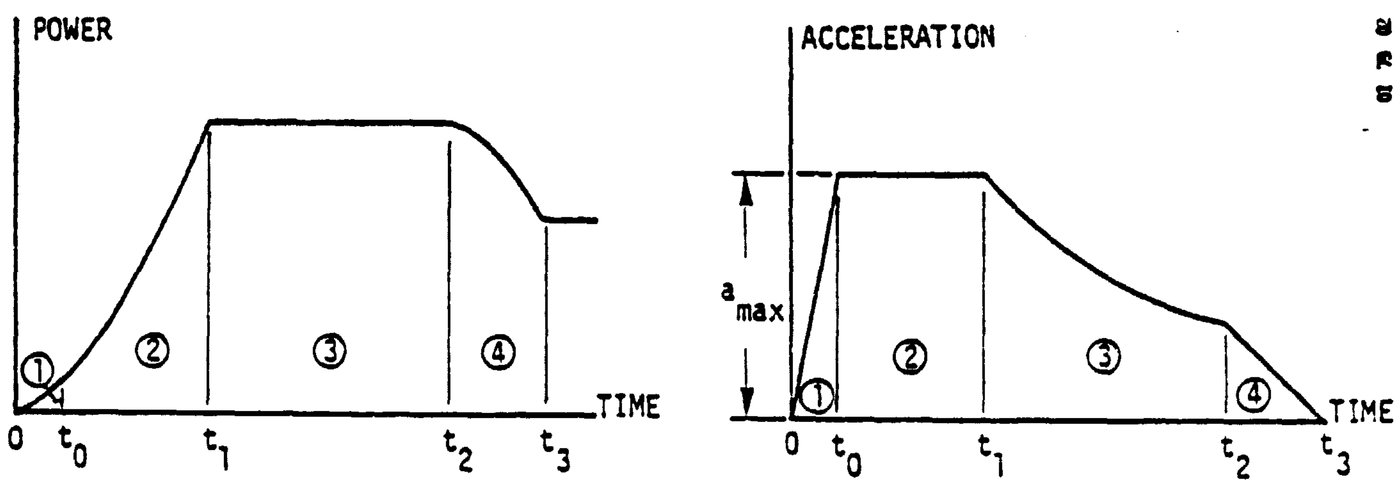


Figure B-2. Nature of J227a(B) Acceleration Phase

When the velocity is zero, so is the power, which means that a constant power acceleration phase is not possible. Moreover, the presence of the acceleration term dV/dt means that the power demanded at cruise will be less than the power during acceleration at the same velocity, since $C_3 > 0$. Finally, a discontinuous acceleration profile was not hypothesized, since the resulting jerk (the derivative of acceleration) would be uncomfortable to passengers, and since the driver/vehicle system would be unable to produce such a response. Therefore, we assumed that the first and fourth segments of the acceleration phase would be characterized by a linear acceleration versus time profile. In summary, the four segments are as shown in Table B-1.

Table B-1. The Four Segments of the Acceleration Phase

Segment	Time	Characteristics
1	$0 \leq t \leq t_0$	Linear Acceleration
2	$t_0 \leq t \leq t_1$	Constant Acceleration
3	$t_1 \leq t \leq t_2$	Constant power
4	$t_2 \leq t \leq t_3$	Linear Acceleration

Consequently, the acceleration history during the first three segments can be described as follows:

$$\frac{dV}{dt} = \begin{cases} a_{max} \left(\frac{t}{t_0}\right) & 0 \leq t \leq t_0 \\ a_{max} & t_0 \leq t \leq t_1 \\ \frac{1}{C_3} \left[\frac{P_1}{V} - C_0 - C_1 V - C_2 V^2 \right] & t_1 \leq t \leq t_2 \\ a_2 \left[1 - \frac{t - t_2}{t_3 - t_2} \right] & t_2 \leq t \leq t_3 \end{cases} \qquad \text{(B-2)}$$

in which the acceleration values a_{max} and a_2 and the time values t_0, t_1, t_2 and t_3 are to be determined. Using the anticipated characteristics of the NTHV, solution of these equations results in

$$t_0 = 1.0 \text{ sec}$$

$$t_1 = 4.0 \text{ sec}$$

$$t_2 = 16.0 \text{ sec}$$

$$t_3 = 19.0 \text{ sec},$$

and in the displacements, velocities, accelerations and powers of Table B-2.

Table B-2. Properties of the Acceleration Phase of J227a(B)*

Time (sec)	Distance (meter)	Velocity (kph)	Acceleration (m/sec^2)	Power (kw)
1.	0.16	1.75	0.970	0.944
2.	1.13	5.24	0.970	2.836
3.	3.07	8.73	0.970	4.737
4.	5.98	12.22	0.970	6.649
5.	9.81	15.24	0.737	6.649
6.	14.39	17.64	0.608	6.649
7.	19.58	19.67	0.523	6.649
8.	25.29	21.43	0.461	6.649
9.	31.47	23.00	0.413	6.649
10.	38.06	24.42	0.375	6.649
11.	45.02	25.71	0.344	6.649
12.	52.33	26.90	0.317	6.649
13.	59.96	28.00	0.295	6.649
14.	67.88	29.03	0.275	6.649
15.	76.08	29.98	0.257	6.649
16.	84.54	30.88	0.242	6.649
17.	98.22	31.61	0.161	5.630
18.	102.07	32.04	0.081	4.506
19.	111.00	32.19	0.000	3.310

*These data are plotted on Figure B-3.

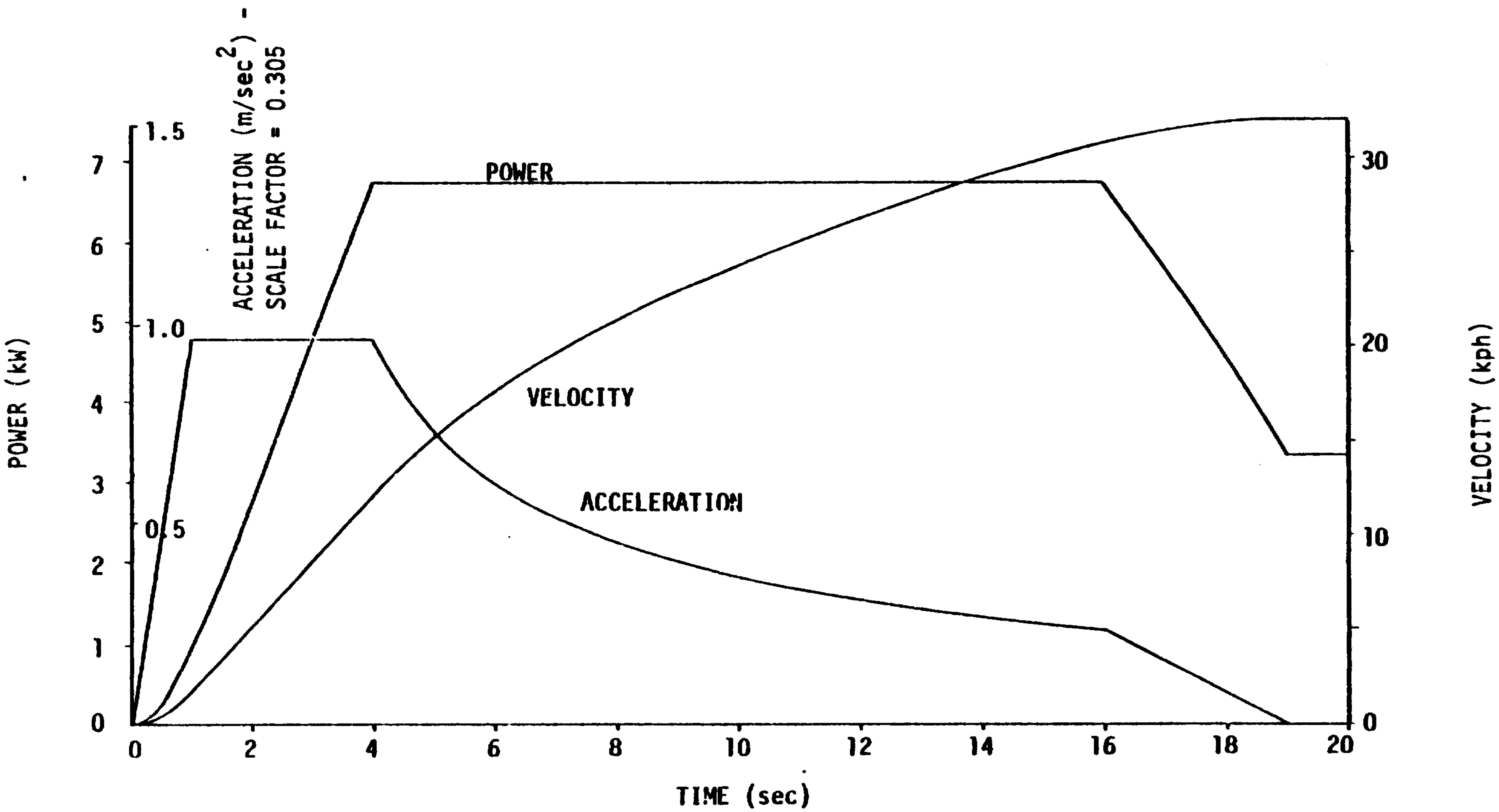


Figure B-3. Acceleration Phase of J227a(B) Cycle

B.1.2 Coast-Down Phase

In the coast-down phase the vehicle was assumed to be rolling with its transmission in gear and its clutch engaged. The velocity-time profile can be obtained by solving the equation of motion:

$$M_e \frac{dV}{dt} = -R_r - R_d + R_E \quad , \tag{B-3}$$

where M_e is the effective mass, including the effect of the rotating components, R_E is the forward tractive force from the powertrain, and R_r and R_d are rolling resistance and aerodynamic drag, respectively. The relationship between R_E and vehicle speed depends on engine braking torque at various engine speeds, which depend in turn on the gear ratios, final drive ratio, and rolling radius. For computation purposes we used empirical data for the Volkswagen Rabbit diesel engine, operating in fourth gear.

When the NTHV is operating with just the heat engine, such data may well be representative. On the other hand, in the all-electric mode the nature of the torque-speed curve would depend on motor losses and on regenerative braking torque. At this point, regenerative braking has not been studied in detail, but it would appear desirable to have the "feel" of the car during coast-down be representative of a conventional automobile. Therefore, these data could well represent a desirable attribute for an NTHV in both the all-electric and the combined modes.

Substitution of typical expressions for R_r and R_d, coupled with the relationship between motoring torque and speed, results in a differential equation identical in form to the third of Equations B-2. Solution of this equation produces the values shown in Table B-3.

Table B-3. Properties of the Coast-down Phase of J227a(B)

Time (sec)	Distance (meters)	Velocity (kph)	Acceleration (m/sec^2)	Power (kw)
39	289.61	30.60	-0.438	3.097
40	297.92	29.04	-0.431	2.894
41	305.79	27.50	-0.424	2.701
42	313.24	25.99	-0.417	2.517

B.1.3 Braking Phase

The goal was to decrease the speed of the vehicle from 25.99 to zero kph in 5 seconds, with a deceleration profile representative of actual driving. Typical braking behavior involves a decreasing deceleration, so that jerk is minimized as the vehicle comes to a stop. Therefore the braking torque at V = 0 was assumed to be zero. The retarding force at V = 0 would then be due only to a rolling resistance at zero velocity. Assumption of a linear deceleration profile results in the data shown in Table B-4.

Table B-4. Properties of the Braking Phase of J227a(B)

Time (sec)	Distance (meters)	Velocity (kph)	Acceleration (m/sec^2)
42	313.24	25.99	-2.709
43	319.19	25.15	-2.203
44	322.93	14.85	-1.697
45	324.98	7.23	-1.191
46	325.84	2.28	-0.685
47	326.01	0	-0.178

B.1.4 Complete Cycle

Plotting the results of these calculations yields the speed profile shown in Figure B-4. Parametric descriptors of the J227a(B) driving cycle are listed in Table B-5.

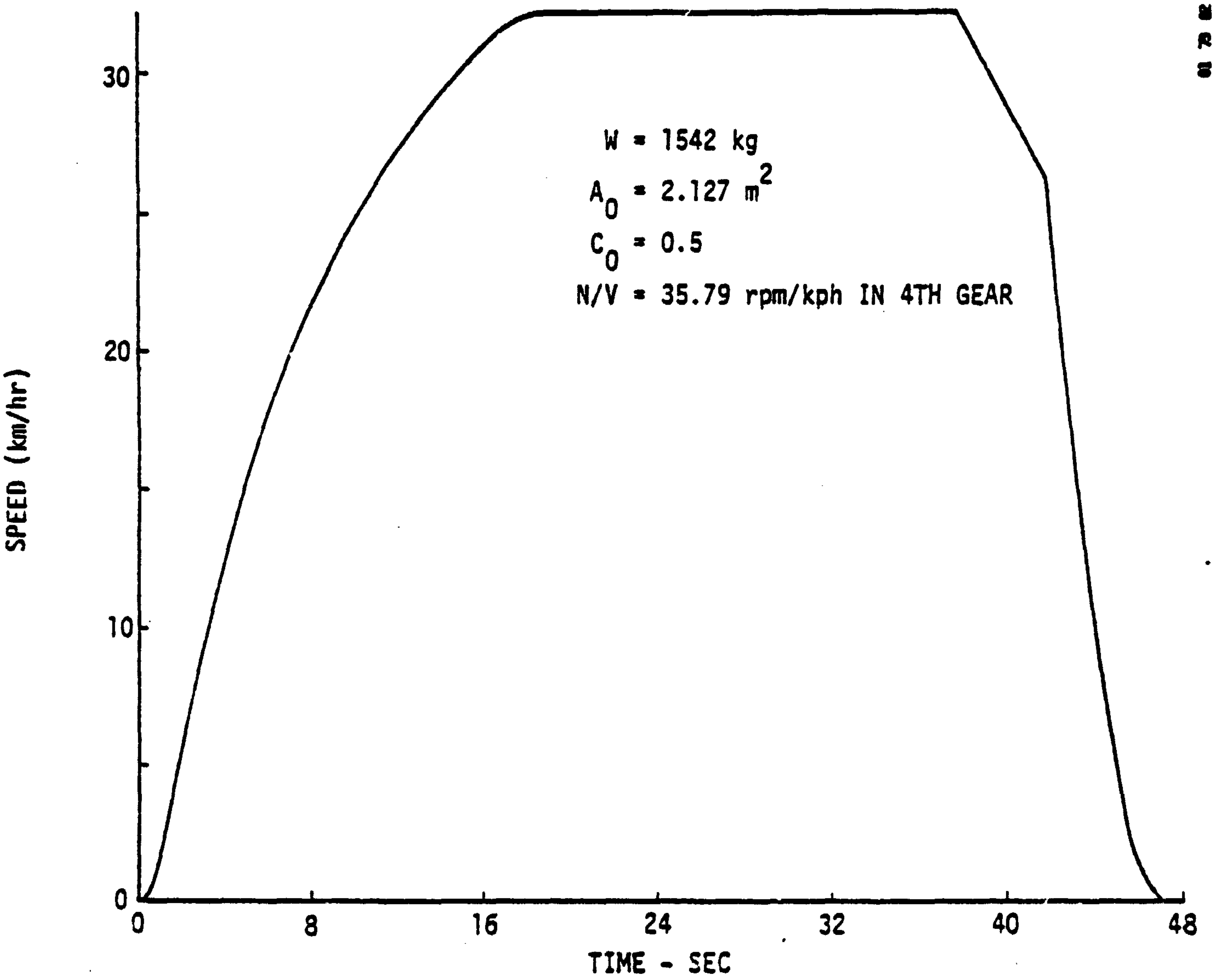


Figure B-4. J227a(B) Cycle

Table B-5. Summary of J227a(B) Cycle

Segment Number	Description	Time Interval (sec)	Peak Acceleration (Gs)	Average Speed (kph)	Distance Traveled (meter)
1	Linear Acceleration	0-1	0.099	0.59	0.16
2	Constant Acceleration	1-4	0.099	6.98	5.82
3	Constant Power	4-16	0.099	23.57	78.56
4	Linear Acceleration	16-19	0.025	31.75	26.46
5	Constant Velocity	19-38	0	32.19	169.88
6	Coast Down	38-42	-0.045	29.13	32.37
7	Linear Deceleration to Stop	42-47	-0.276	9.20	12.77
8	Idle	47-72	0	0	0
	TOTAL	0-72	-0.276 to +0.099	16.30	326.01

B.2 ESTABLISHING DRIVING CYCLES IN TERMS OF J227a(B), FUDC, FHDC

B.2.1 Applications of Combined Driving Cycles

Some of the objectives of the Task 1 and Task 2 efforts may be summarized as follows:

1. To characterize daily trip making

2. To evaluate the petroleum consumption of the reference ICE vehicle when used over the distribution of daily driving

3. To evaluate the NTHV petroleum consumption when operated similarly

4. To define the operating strategy of the NTHV so that it demonstrates good potential for reducing petroleum consumption in the daily driving patterns.

Fuel economy simulations, such as CARSIM, have an integral role in achieving all of these objectives, but their uses will probably vary substantially. Specifically, the design of the operational strategy (objective 4) is concerned with the particulars of vehicle operation, since the vehicle's computer will have to make operating decisions based on the particular information available to it at any given moment. On the other hand, for objectives 1 through 3, the driving cycle parameters must be treated statistically (and hence in less detail), since we are dealing with a fleet of automobiles operating under a wide variety of conditions.

This difference in application becomes obvious when one starts to construct representative driving cycles. The design and testing of the operational strategy require a specific velocity-time profile, or series of profiles, so that the decision making process can be scrutinized. For example, if one were simulating a 5 km trip, of which 2 km were represented by the J227a(B) cycle and 3 km by the Federal Urban Driving Cycle (FUDC), then one would need to generate a 5 km profile with specific portions drawn from each of the driving cycles and appropriately combined so as to evaluate the strategy's ability to cope with a variety of specific situations. Constructing such profiles is basically the problem that the EPA faced when it originally formulated the city and highway driving cycles, and it is no easy task. However, this level of detail is neither necessary nor appropriate in order to evaluate fleet fuel economy. Therefore, for the present time, we have adopted a second approach.

The basic approach is to obtain the petroleum consumption values (by CARSIM or other means) for a single pass through each of the three cycles—J227a(B), FUDC and FHDC. These values are then multiplied by various factors and summed (to reflect the distance traveled in any one cycle, plus any other conditions which might affect fuel economy). This will require, at least for the reference ICE vehicle, the use of CARSIM only once for each of the three cycles.

B.2.2 Literature Survey

A brief review of the literature seems to indicate that the only non-vehicle factors which have a quantifiable effect on petroleum consumption (at least for the purposes of this program) are ambient temperatures and warm-up. Reference B-1 is a 1965 General Motors study in which a proving ground warm-up fuel economy test, consisting of a cold start from ambient temperature followed by four cycles of the General Motors Simulated City Fuel Economy Schedule, was used. Since the study used vehicles from the early 1960s, and since its driving cycles do not correspond with those used in this program, the results are not reliable for our purposes. Reference B-2 is a recent Canadian research study focusing mostly on emissions. No warm-up data (such as fuel economy versus trip length) are given. The ambient temperature effects are described only by means of regression equations. These data were thus considered to be too crude for our needs. Reference B-3 is a report focusing on CO emissions, but which has useful information on warm-up transients at various ambient temperatures. Reference B-4 is a study performed at the Department of Energy, Bartlesville. It reports both ambient temperature and warm-up effects. Unfortunately, the fuel economy data were averaged over the four vehicles tested, which ranged from a four-cylinder subcompact to an eight-cylinder full size car. By normalizing these data to fully warmed-up FUDC and FHDC fuel economy, however, the effects of this averaging should be minimized. Reference B-4 reports cumulative rather than "instantaneous" values, so the latter were deduced formally. Some minor inconsistencies in the data were uncovered, even though the normalization procedure tended to minimize such effects.

B.2.3 Data Analysis

The most pertinent data from Reference B-4 are summarized in Tables B-6 through B-9, which are simply reproductions of its Tables 2, 4, 5 and 6. Processed forms of these data are presented in Tables B-10 through B-14. The FTP fuel economy noted in Tables B-10 through B-13 were calculated from the formula

$$FE_{FTP} = \frac{1}{\frac{0.2054}{FE_1} + \frac{0.5223}{FE_2} + \frac{0.2723}{FE_3}} , \qquad \text{(B-4)}$$

where the subscripts 1, 2 and 3 indicate the fuel economy measured for the first, second and third bags of the Federal Test Procedure. The derivation of this formula is based on the use of the carbon balance method for measuring fuel consumption. Note that the resulting fuel economy values are somewhat different from those indicated in Table B-9.

The numbers shown in Table B-14 were calculated on the expectation of an exponential convergence to the fully warmed-up city fuel as the trip length increased beyond 10 miles (16 km). The logarithmic plot of these data in Figure B-5 shows that this assumption is not fully accurate. However, the faired curves were used to generate the factors used subsequently in the analysis. The lack of fit to these curves is largely due to the non-uniform nature of the driving cycle. Reference B-4 shows some comparisons to the warm-up rate for steady cruise, which is much smoother. Table B-15 presents warm-up data for highway driving from a cold start.

Table B-6. Modified 1975 FTP and HWFET Driving Schedule

Designation	Time Interval, Minutes	Cumulative Distance, Miles
Cold transient.......	0 - 8.4	3.6
Stabilized...........	8.4 - 22.9	7.5
Soak.................	22.9 - 32.9	7.5
Hot transient........	32.9 - 41.3	11.0
Idle.................	41.3 - 48.3	11.0
Highway warmup (Highway No. 1)....	48.3 - 61.0	21.3
Idle.................	61.0 - 64.0	21.3
Highway fuel economy (Highway No. 2)....	64.0 - 76.8	31.6

NOTE.-No measurements were made during soak or idle periods.

Table B-7. Fuel Consumption for Discrete Test Segments — Four Car Averages

Trip, Miles*	Fuel Economy, mpg			
	20°F	45°F	70°F	100°F**
0 - 3.6	9.6	11.3	12.9	12.0
0 - 7.5	11.1	12.4	13.5	12.2
0 - 11.1	11.9	13.0	14.0	12.5
0 - 21.3	14.6	15.5	16.3	14.5
0 - 31.6	16.0	16.7	17.4	15.5
21.3 - 31.6	20.6	20.8	21.2	18.6.
	Fuel Consumed, Gallons/100 Miles			
	20°F	45°F	70°F	100°F**
0 - 3.6	10.46	8.82	7.78	8.35
0 - 7.5	9.01	8.05	7.39	8.20
0 - 11.1	8.38	7.69	7.15	8.00
0 - 21.3	6.85	6.46	6.15	6.90
0 - 31.6	6.25	5.99	5.75	6.47
	Highway Fuel Consumed, Gallons/100 Miles			
	20°F	45°F	70°F	100°F**
21.3 - 31.6	4.85	4.80	4.72	5.38

*Trip miles represent the cumulative mileage in sequential completion of test segments as described in Table 1.
**100° F tests with air conditioner in operation.

Table B-8. Cumulative Fuel Economy at 1-Mile Intervals of the Federal Test Procedure — Four-Vehicle Average

Distance, Miles	Fuel Economy, mpg 20°	45°	70°	100°*
0.9	6.0	8.1	10.5	11.1
1.79	7.8	9.6	12.2	12.6
2.69	9.4	11.3	13.4	12.6
3.59	10.0	11.9	13.5	12.4
4.53	10.3	11.9	13.4	12.4
5.54	11.2	12.9	14.2	12.9
6.53	11.6	13.2	14.4	12.8
7.50	11.6	13.1	14.2	12.5
8.44	11.7	13.1	14.2	12.5
9.24	12.0	13.3	14.4	12.7
10.14	12.4	13.7	14.7	12.9
11.04	12.5	13.7	14.7	12.9

*With air conditioner in operation.

Table B-9. Ambient Temperature and Fuel Consumption — Four-Vehicle Average

Test Cycle	Test Temperature, °F 20	45	70	100*
FTP Fuel Economy, Miles Per Gallon				
City	12.9	13.9	14.8	13.1
City/Highway	15.5	16.3	17.1	15.1
Highway	20.6	20.9	21.2	18.6
FTP Fuel Consumption, Gallons/100 Miles				
City	7.79	7.20	6.76	7.65
City/Highway	6.47	6.12	5.84	6.62
Highway	4.85	4.80	4.72	5.38
FTP Fuel Consumption, % Increase Over 70° Test				
City	15	7	Base	13
City/Highway	11	5	Base	13
Highway	3	2	Base	14

*With air conditioner in operation.

Table B-10. Fuel Consumption Data at 20°F

Segment	Length of Segment	Cumulative Trip Length	Total Fuel Used	$\frac{\text{Cum FE}}{FE_{FTP}}$	Fuel Used This Segment	Fuel Econ. This Segment	$\frac{\text{FE This Segment}}{\text{FE HWFET}_{70}}$
Cold Transient	3.576	3.576	0.3740	0.7729	0.3740	9.5602	
Stabilized	3.910	7.486	0.6745	0.8973	0.3004	13.0143	
Hot Transient	3.576	11.062	0.9270	0.9647	0.2525	14.1620	
Highway Warmup	10.2	21.262	1.4564		0.5295	19.2652	0.947
Highway Fuel Econ.	10.2	31.462	1.9664		0.5099	20.0028	0.983

$FE_{FTP} = 12.37$ mpg

Table B-11. Fuel Consumption Data at 45°F

Segment	Length of Segment	Cumulative Trip Length	Total Fuel Used	$\frac{\text{Cum FE}}{FE_{FTP}}$	Fuel Used This Segment	Fuel Econ. This Segment	$\frac{\text{FE This Segment}}{\text{FE HWFET}_{70}}$
Cold Transient	3.576	3.576	0.3154	0.8545	0.3154	11.3379	
Stabilized	3.910	7.486	0.6026	0.9363	0.2872	13.6133	
Hot Transient	3.576	11.062	0.8507	0.9801	0.2480	14.4168	
Highway Warmup	10.2	21.262	1.3735		0.5229	19.5082	0.959
Highway Fuel Econ.	10.2	31.462	1.8846		0.5110	19.9590	0.981

$FE_{FTP} = 13.27$ mpg

Table B-12. Fuel Consumption Data at 70°F

Segment	Length of Segment	Cumulative Trip Length	Total Fuel Used	$\frac{\text{Cum FE}}{FE_{FTP}}$	Fuel Used This Segment	Fuel Econ. This Segment	$\frac{\text{FE This Segment}}{\text{FE HWFET}_{70}}$
Cold Transient	3.576	3.576	0.2782	0.9102	0.2782	12.8535	
Stabilized	3.910	7.486	0.5532	0.9583	0.2750	14.2180	
Hot Transient	3.576	11.062	0.7909	0.9904	0.2377	15.0431	
Highway Warmup	10.2	21.262	1.3076		0.5167	19.7414	0.971
Highway Fuel Econ.	10.2	31.462	1.8091		0.5015	20.3409	1.000

$FE_{FTP} = 14.12$ mpg

Table B-13. Fuel Consumption Data at 100°F with Air Conditioning

Segment	Length of Segment	Cumulative Trip Length	Total Fuel Used	$\frac{\text{Cum FE}}{FE_{FTP}}$	Fuel Used This Segment	Fuel Econ. This Segment	$\frac{\text{FE This Segment}}{\text{FE HWFET}_{70}}$
Cold Transient	3.576	3.576	0.2986	0.9570	0.2986	11.9760	
Stabilized	3.910	7.486	0.6139	0.9745	0.3153	12.4026	
Hot Transient	3.576	11.062	0.8850	0.9988	0.2711	13.1903	
Highway Warmup	10.2	21.262	1.4671		0.5821	17.5222	0.861
Highway Fuel Econ.	10.2	31.462	2.0356		0.5685	17.9415	0.882

$FE_{FTP} = 12.51$ mpg

Table B-14. Cumulative Fuel Consumption Data

	20° F		45° F		70° F		100° F	
Trip Length-Miles	Cum FE	$1-\frac{\text{Cum FE}}{FTP_{70}}$	Cum FE	$1-\frac{\text{Cum FE}}{FTP_{70}}$	Cum FE	$1-\frac{\text{Cum FE}}{FTP_{70}}$	Cum FE	$1-\frac{\text{Cum FE}}{FTP_{70}}$
0.90	6.0	.5946	8.1	.4527	10.5	.2905	11.1	.2500
1.79	7.8	.4730	9.6	.3514	12.2	.1757	12.6	.1486
2.69	9.4	.3649	11.3	.2365	13.4	.0946	12.6	.1486
3.59	10.0	.3243	11.9	.1959	13.5	.0878	12.4	.1622
4.53	10.3	.3041	11.9	.1959	13.4	.0946	12.4	.1622
5.54	11.2	.2432	12.9	.1284	14.2	.0405	12.9	.1284
6.53	11.6	.2162	13.2	.1081	14.4	.0270	12.8	.1351
7.50	11.6	.2162	13.1	.1149	14.2	.0405	12.5	.1554
8.44	11.7	.2095	13.1	.1149	14.2	.0405	12.5	.1554
9.24	12.0	.1892	13.3	.1014	14.4	.0270	12.7	.1419
10.14	12.4	.1622	13.7	.0743	14.7	.0068	12.9	.1284
11.04	12.5	.1554	13.7	.0743	14.7	.0068	12.9	.1284
	$FTP_{20} = 12.9$		$FTP_{45} = 13.9$		$FTP_{70} = 14.8$		$FTP_{100} = 13.1$	
Highway FE		20.62		20.85		21.19		18.59
Hwy. FE/Hwy. FE_{70}		0.973		0.984		1.000		0.877

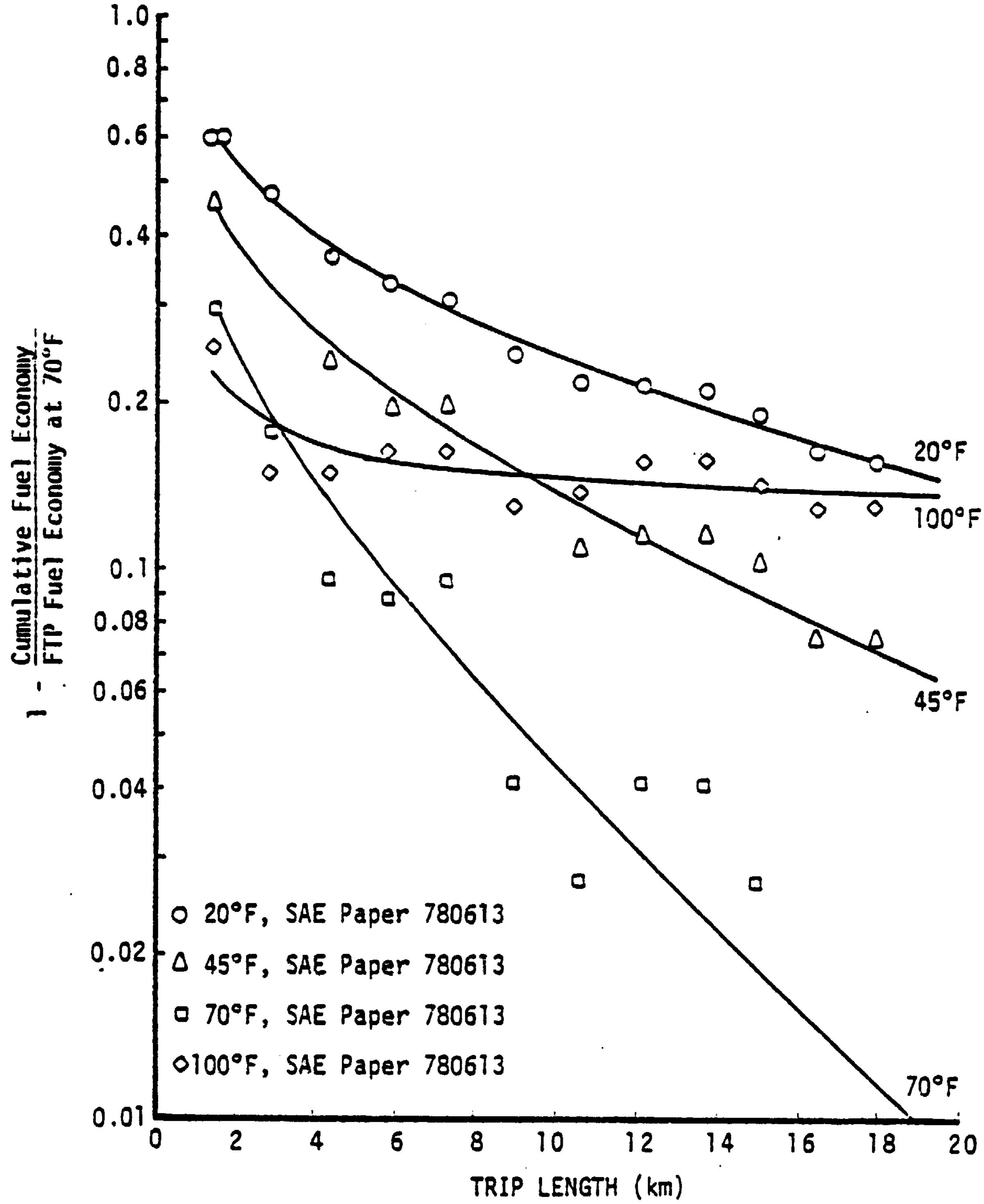


Figure B-5. Fuel Economy Residual versus Trip Length

Table B-15. Ratio of Cold-Start Highway Fuel Economy to Standard Highway Fuel Economy*

Vehicle	Tires	Cold FE / FE HWFET
1976 Pinto	Radial	0.880
	Bias	0.904
1976 Granada	Radial	0.904
1976 Aspen Wagon	Radial	0.923
1976 Impala	Radial	0.935
Average		0.914

*Source: Table 10 of Reference B-5

B.2.4 Combination of Driving Cycles

The next step in the analysis is to combine the J227a(B) cycle, the FUDC and the FHDC so as to match observed driving behavior. The Technical Proposal, Volume I, pages 2-16 through 2-26, presented two different ways of matching observed driving behavior: on the basis of stops per mile, and on the basis of average speed. Therefore, we proceeded to repeat the calculations done in the proposal, using the updated average speed in the J227a(B) cycle (see Section B.1) for the mean trip lengths in each trip length category (column 6, Table 2-2, page 2-33 of the Technical Proposal). The results of using Equation B-5,

$$a = \frac{\frac{1}{V_o} - \frac{1}{V_B}}{\frac{1}{V_A} - \frac{1}{V_B}} , \qquad \text{(B-5)}$$

to determine the fraction of driving in each driving cycle are shown in Table B-16. For each trip length the lower speed driving was split equally into two parts, with one occurring in the beginning of the trip, and the other occurring at the end. Presumably, this would account for the use of arterial highways wherever possible, with entry to and exit from each highways occurring near the origin and destination of each trip. The

Table B-16. Trip Composition for Various Trip Lengths

Trip Length Category (km)	Length (km)	Average Trip Speed (kph)	Trip Description (Kilometers in J227a(B) Cycle, FUDC, & FHDC)
Under 8.0	2.96	17.2	1.316 J227a(B), 0.327 FUDC, 1.316 J227a(B)
8.0-15.3	10.14	32.5	4.81 FUDC, 0.507 FHDC, 4.81 FUDC
15.3-24.9	19.5	43.5	5.25 FUDC, 9.00 FHDC, 5.25 FUDC
24.9-33.0	30.4	54.7	4.35 FUDC, 21.7 FHDC, 4.35 FUDC
33.0-49.1	42.0	64.7	2.86 FUDC, 36.2 FHDC, 2.86 FUDC
49.1-65.2	60.0	79.5	60.0 FHDC
65.2-81.3	78.4	79.5	78.4 FHDC
81.3-160.1	113.3	79.5	113.3 FHDC
160.1+	309	79.5	309 FHDC

cycle speeds used to establish the distances shown in Table B-16 are as follows: 16.30 kph in J227a(B), 31.5 kph in FUDC and 77.6 kph in FHDC. Cycle lengths are 0.326, 12.05 and 16.4 km, respectively.

B.2.5 Fuel Consumption Factors: Methodology and Sample Calculations

Having established the distances, the next step was to identify the appropriate factors from Figure B-5 for use with the fuel consumption calculated from CARSIM. Lacking information regarding fuel consumption factors for the SAE J227a(B) cycle, the factors used were those for the FUDC. The procedure may be illustrated by considering a trip length of 10.1 km. The first segment of such a trip is 4.81 km of driving in the FUDC. The second segment is 0.507 km in the FHDC, and the third is 4.81 km in the FUDC. The fuel consumption in this trip is given by

$$C = \frac{4.81}{12.05}\left(\frac{1}{f_1}\right) C_{UDC} + \frac{0.507}{16.4}\left(\frac{1}{f_2}\right) C_{HDC} + \frac{4.81}{12.05}\left(\frac{1}{f_3}\right) C_{UDC} \quad , \tag{B-6}$$

where C_{UDC} is the fuel consumption in a single urban driving cycle at standard conditions (68°F to 86°F), C_{HDC} is the fuel consumption in a fully warmed-up highway driving cycle at standard conditions, and f_1, f_2, and f_3 are the warm-up factors applied to the fuel economy of segments 1, 2 and 3, respectively. The form of Equation B-6 comes from a definition of the f-factors:

$$FE_{actual} = f(FE_{ideal}) \quad . \tag{B-7}$$

Since

$$C = \frac{\text{DISTANCE DRIVEN}}{FE_{actual}} = \frac{\text{DISTANCE DRIVEN}}{f(FE_{ideal})} \quad , \tag{B-8}$$

we can write

$$C = \frac{1}{f} C_{ideal} \tag{B-9}$$

for each segment of the trip. The f-factors are obtained from Figure B-5, using appropriate assumptions for the amount of warmup that takes place.

As an example, the first segment is 4.81 km of the FUDC; the values of the quantity $1-f_1$ are read from Figure B-5 for a trip length of 4.81 km, assuming a cold start. (Warm starts will be treated at the end of this section.) The resulting values of f_1 and $1/f_1$ are shown in Table B-17a.

The second segment of the trip is 0.507 km in the FHDC. Since Figure B-5 applies to city driving from a cold start, it would not be appropriate to apply these data to the 0.507 km of highway driving from a partially warmed-up condition. On the other hand, warm-up factors f for the FHDC from a cold start at 70°F were assumed to be 0.914 at 16.4 km (Table B-15), 0.971 at 32.8 km

Table B-17. Fuel Consumption Factors for Trip Length of 10.1 Kilometers from Cold Start

B-17a. First Segment: 4.81 km in FUDC

Ambient Temperature	$1-f_1$	f_1	$1/f_1$
20°F	0.359	0.641	1.56
45°F	0.237	0.763	1.31
70°F	0.118	0.862	1.13
100°F	0.160	0.840	1.19

B-17b. Second Segment: 0.507 km in FHDC

Ambient Temperature	f_2	$1/f_2$
20°F	0.891	1.122
45°F	0.903	1.107
70°F	0.914	1.094
100°F	0.851	1.175

B-17c. Third Segment: 4.81 km of FUDC

Ambient Temperature	f_2	$1/f_3$
20°F	0.872	1.15
45°F	0.939	1.06
70°F	1.000	1.00
100°F	0.885	1.13

(Table B-12), and 1.00 at 49.2 km. Some way must be found to combine the city and highway warm-up factors for trips in which a segment of FHDC follows a segment of FUDC. For the purposes of this study, this was done by applying the "cold" f-factor to a highway driving distance equal to the first 16.4 km in the FHDC minus twice the original distance in the FUDC. The next 16.4 km in the FHDC would use the "warm" f-factor, and the remainder would use the "hot" f-factor. For the particular example being described, 0.507 km of FHDC is less than

16.4 - 2 × 4.81, so at 70°F the entire FHDC segment gets a factor f_2 of 0.914, as indicated in Table B-17b. The array of fuel consumption factors for FHDC "cold" starts (one highway cycle), "warm" starts (two cycles), and "hot" starts (three cycles) is indicated in Table B-18.

Table B-18. Fuel Consumption Factors for the Federal Highway Driving Cycle

Ambient Temperature	"Cold" Starts f	1/f	"Warm" Starts f	1/f	"Hot" Starts f	1/f
20°F	0.891*	1.122	0.947	1.056	0.983	1.017
45°F	0.903*	1.107	0.959	1.043	0.981	1.019
70°F	0.914	1.094	0.971	1.030	1.000	1.000
100°F	0.841*	1.175	0.861	1.161	0.882	1.134

*Extrapolated from 70°F value and other values in the absence of actual data.

The third segment of this trip is 4.81 km of the FUDC (starting at 5.32 km and ending at 10.13 km). One could make an argument that this would correspond roughly to the "stabilized" portion of the driving cycle of Reference B-4 (see Tables B-10 through B-14), but the fuel economy in this segment is higher than the reported FTP fuel economy, and that seems unreasonably optimistic. Therefore, the f-factors were based on the FTP fuel economy reported in Table B-9. [For example, the value of f_3 for 20°F was determined by dividing the FTP fuel economy at 20°F (12.9 mph) by the FTP fuel economy at 70°F (14.8 mph).] These values are shown in Table B-17c. The values of Table B-17 can then be used to calculate the fuel consumption for the trip of 10.1 km:

$$C = 0.400 \left(\frac{1}{f_1} + \frac{1}{f_3}\right) C_{UDC} + 0.031 \frac{1}{f_2} C_{HDC} , \qquad \text{(B-10)}$$

where

$$\frac{1}{f_1} + \frac{1}{f_3} = \begin{cases} 2.707 & 20° \\ 2.375 & 45° \\ 2.133 & 70° \\ 2.320 & 100° \end{cases} . \qquad \text{(B-11)}$$

For trips that do not correspond to a cold start (for example, a trip which begins an hour after a previous trip), the assumption of a cold start is not valid. Different factors are required to represent this "warm" start. Lacking data about such factors, we assumed that they would correspond to the addition of some fixed distance (say, 3.22 km) to the trips made from a cold start. In other words, Figure B-5 could be used to generate the f-factors by adding 3.22 km to the trip length for the first segment, so that f-factors corresponding to 8.03 km, instead of 4.81 km, would be used. For the second and third segments of the trip, the f-factors would be the same. The new values of f_1, $1/f_1$, and $1/f_1 + 1/f_3$ are shown in Table B-19.

Table B-19. Fuel Consumption Factors for Trip Length of 10.1 Kilometers from Warm Start

Ambient Temperature	$1-f_1$	f_1	$1/f_1$	$\frac{1}{f_1}+\frac{1}{f_3}$
20°F	0.273	0.727	1.376	2.523
45°F	0.164	0.836	1.196	2.261
70°F	0.061	0.939	1.066	2.066
100°F	0.148	0.852	1.174	2.303

B.2.6 Summary

Similar logic was used for the remaining trip lengths. The particular assumptions are indicated in Table B-20. The results are as follows:

Table B-20. Assumptions for Various Trip Lengths (TL)

TL = 2.96 kilometers: Use same factors for SAE J227a (B) and FUDC.

TL = 10.14, 19.5, 30.4, 42.0 kilometers:
Apply "cold" FHDC factors to first 16.4 km of FHDC minus twice the first segment FUDC distance; apply "warm" FHDC to the remainder of highway driving; use FTP fuel economy for last FUDC segment.

TL = 60.0, 78.4, 113.3, and 309 kilometers:
Apply "cold" FHDC factors to first 16.4 km; apply "warm" FHDC factors to second 16.4 km, and apply "hot" FHDC factors to the remainder.

$$TL = 2.96: \quad C = K_{13}\,[7.877\,C_{227} + 0.0271\,C_{UDC}] \tag{B-12}$$

where

$$K_{13} = \left\{\begin{array}{ccc} \underline{\text{Cold}} & & \underline{\text{Warm}} \\ 2.439 & 20^\circ & 1.460 \\ 1.818 & 45^\circ & 1.250 \\ 1.408 & 70^\circ & 1.094 \\ 1.290 & 100^\circ & 1.181 \end{array}\right. \tag{B-13}$$

$$TL = 10.14: \quad C = 0.400\,K_{13}\,C_{UDC} + 0.031\,K_2\,C_{HDC} \tag{B-14}$$

where

$$K_{13} = \left\{\begin{array}{ccc} \underline{\text{Cold}} & & \underline{\text{Warm}} \\ 2.707 & 20^\circ & 2.523 \\ 2.375 & 45^\circ & 2.261 \\ 2.133 & 70^\circ & 2.066 \\ 2.320 & 100^\circ & 2.303 \end{array}\right. \qquad K_2 = \left\{\begin{array}{cc} 1.122 & 20^\circ \\ 1.107 & 45^\circ \\ 1.094 & 70^\circ \\ 1.175 & 100^\circ \end{array}\right. \tag{B-15}$$

$$TL = 19.5: \quad C = 0.435\, K_{13}\, C_{UDC} + 0.548\, K_2\, C_{HDC} \tag{B-16}$$

where

$$\begin{array}{cc} & \begin{array}{ccc} \underline{\text{Cold}} & & \underline{\text{Warm}} \end{array} \\ K_{13} = & \left\{ \begin{array}{ccc} 2.400 & 20^\circ & 2.234 \\ 2.209 & 45^\circ & 2.108 \\ 2.057 & 70^\circ & 1.999 \\ 2.135 & 100^\circ & 2.121 \end{array} \right. \end{array} \qquad K_2 = \left\{ \begin{array}{cc} 1.100 & 20^\circ \\ 1.086 & 45^\circ \\ 1.073 & 70^\circ \\ 1.170 & 100^\circ \end{array} \right. \tag{B-17}$$

$$TL = 30.4: \quad C = 0.361\, K_{13}\, C_{UDC} + 1.323\, K_2\, C_{HDC} \tag{B-18}$$

where

$$\begin{array}{cc} & \begin{array}{ccc} \underline{\text{Cold}} & & \underline{\text{Warm}} \end{array} \\ K_{13} = & \left\{ \begin{array}{ccc} 2.481 & 20^\circ & 2.270 \\ 2.257 & 45^\circ & 2.139 \\ 2.087 & 70^\circ & 2.011 \\ 2.144 & 100^\circ & 2.124 \end{array} \right. \end{array} \qquad K_2 = \left\{ \begin{array}{cc} 1.080 & 20^\circ \\ 1.066 & 45^\circ \\ 1.053 & 70^\circ \\ 1.666 & 100^\circ \end{array} \right. \tag{B-19}$$

$$TL = 42.0: \quad C = 0.238\, K_{13}\, C_{UDC} + 2.210\, K_2\, C_{HDC} \tag{B-20}$$

where

$$\begin{array}{cc} & \begin{array}{ccc} \underline{\text{Cold}} & & \underline{\text{Warm}} \end{array} \\ K_{13} = & \left\{ \begin{array}{ccc} 2.725 & 20^\circ & 2.342 \\ 2.391 & 45^\circ & 2.173 \\ 2.175 & 70^\circ & 2.037 \\ 2.172 & 100^\circ & 2.129 \end{array} \right. \end{array} \qquad K_2 = \left\{ \begin{array}{cc} 1.066 & 20^\circ \\ 1.052 & 45^\circ \\ 1.042 & 70^\circ \\ 1.158 & 100^\circ \end{array} \right. \tag{B-21}$$

$$TL = 60.0: \quad C = 3.657\, K_2\, C_{HDC} \tag{B-22}$$

where

$$\begin{array}{cc} & \begin{array}{ccc} \underline{\text{Cold}} & & \underline{\text{Warm}} \end{array} \\ K_{2} = & \left\{ \begin{array}{ccc} 1.056 & 20^\circ & 1.045 \\ 1.050 & 45^\circ & 1.040 \\ 1.034 & 70^\circ & 1.024 \\ 1.153 & 100^\circ & 1.148 \end{array} \right. \end{array} \tag{B-23}$$

$$TL = 78.4: \quad C = 4.775\, K_2\, C_{HDC} \tag{B-24}$$

where

$$K_2 = \left\{ \begin{array}{ccc} \underline{\text{Cold}} & & \underline{\text{Warm}} \\ 1.047 & 20° & 1.039 \\ 1.043 & 45° & 1.035 \\ 1.026 & 70° & 1.018 \\ 1.148 & 100° & 1.145 \end{array} \right. \tag{B-25}$$

$$TL = 113.3: \quad C = 6.902\, K_2\, C_{HDC} \tag{B-26}$$

where

$$K_2 = \left\{ \begin{array}{ccc} \underline{\text{Cold}} & & \underline{\text{Warm}} \\ 1.038 & 20° & 1.032 \\ 1.035 & 45° & 1.030 \\ 1.018 & 70° & 1.013 \\ 1.144 & 100° & 1.142 \end{array} \right. \tag{B-27}$$

$$TL = 309: \quad C = 18.824\, K_2\, C_{HDC} \tag{B-28}$$

where

$$K_2 = \left\{ \begin{array}{ccc} \underline{\text{Cold}} & & \underline{\text{Warm}} \\ 1.025 & 20° & 1.022 \\ 1.025 & 45° & 1.023 \\ 1.007 & 70° & 1.005 \\ 1.138 & 100° & 1.137 \end{array} \right. \tag{B-29}$$

and where

$$\begin{aligned} K_{13} &= \frac{1}{f_1} + \frac{1}{f_3} \\ K_2 &= \frac{1}{f_2} \end{aligned} \tag{B-30}$$

As an example, suppose that

$$\begin{aligned} FE_{227} &= 4.25 \text{ km/liter} \\ FE_{UDC} &= 5.95 \text{ km/liter} \\ FE_{HDC} &= 8.50 \text{ km/liter} \end{aligned} \tag{B-31}$$

Since the J227a(B) cycle, FUDC and FHDC have lengths of 0.326 km, 12.05 km and 16.4 km, respectively, the fuel consumed in each cycle is

$$C_{227} = 0.079 \text{ liter}$$

$$C_{UDC} = 2.024 \text{ liter} \tag{B-32}$$

$$C_{HDC} = 1.931 \text{ liter}$$

Substitution into the previous equations for cold-start fuel economy at 70°F yields the fuel consumption and fuel economy values shown in Table B-21.

Table B-21. Example Fuel Economy Results (70°F)

Trip Length (kilometers)	Fuel Consumption (liters)	Fuel Economy (km/ltr)
2.96	0.949	3.120
10.14	1.794	5.650
19.5	2.949	6.602
30.4	4.217	7.215
42.0	5.496	7.644
60.0	7.298	8.222
78.4	9.456	8.290
113.3	13.56	8.354
309.	36.59	8.443

We realize that the assumptions made here are "strong" in the statistical sense, and may in fact be unrealistic for certain conditions. It is our intention to update these numbers as better information becomes available. But our present concern is primarily with establishing the methodology from start to finish. Single runs of CARSIM over each of the three driving cycles should produce the fuel consumption data that we need for various trip lengths, ambient temperatures and warm-up conditions. It may well be, however, that CARSIM will not be able to distinguish between bags 1 and 3 of the FUDC, since it does not model warm-up. In that case it may be necessary to revise this methodology.

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3. Service, G.R., "CO Hot Spot Preliminary Investigation," U.S. Environmental Protection Agency, TAEB Report 77-13, December 1977.

4. Eccleston, B.H., and Hurn, R.W., "Ambient Temperature and Trip Length - Influence on Automotive Fuel Economy and Emissions," SAE Paper 780613 presented at the Passenger Car Meeting, Troy, Michigan, June 1978.

5. "Dynamometer and Track Measurements of Passenger Car Fuel Economy Influences," Environmental Protection Agency, TAEB Report 77-12, September 1977.

APPENDIX A

MISSION ANALYSIS AND PERFORMANCE SPECIFICATION STUDIES REPORT

VOLUME II

NEAR TERM HYBRID PASSENGER VEHICLE DEVELOPMENT PROGRAM

PHASE I

CONTRACT 955188

MISSION ANALYSIS AND PERFORMANCE SPECIFICATION STUDIES REPORT

VOLUME II

25 JANUARY 1979

SUBMITTED TO:

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1 INTRODUCTION

In designing a near-term hybrid vehicle, it is necessary to first establish a data base which will help to define how the vehicle will be used. The petroleum savings resulting from the use of hybrid vehicles will depend upon the portion of daily travel that can be accomplished on the stored electrical energy. Therefore, the vehicle's design must take into account how the vehicle will be driven: the vehicle's daily range, the frequency of trips, the speed it must attain, the terrain it crosses, where it is parked and so forth. This report contains data which describe the travel patterns of drivers and how they use their vehicles.

To determine the minimum requirements for range, speed, and capacity in typical kinds of driving, a previous GRC study[1] made a detailed new analysis of existing travel data. To delineate the detailed distributions of range and trip frequency, the original data tapes from two extensive urban origin-destination travel surveys[2,3] were processed. Los Angeles was chosen for analysis because of its size and its historic dependence on automotive travel. Washington, D.C. was selected because its survey was made at about the same time as the Los Angeles survey and because it differs from Los Angeles in potentially important ways: it is much smaller, and much more dependent on public transportation. Data from these two surveys correlate well with transportation data taken from other sources. Therefore, when the data from each survey are taken together, the result indicates a range of vehicle use representative of driving in urban areas across the country.

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[1] W. F. Hamilton, Prospects for Electric Cars, General Research Corporation CR-1-704, November 1978.

[2] LARTS Base Year Report: 1967 Origin-Destination Survey, Transportation Association of Southern California, Los Angeles, December 1971.

[3] The Home Interview Survey - What and Why, National Capital Region Transportation Planning Board, Washington, D.C., February 1968.

The bulk of the detailed data in this report is based on the Los Angeles and Washington, D.C. origin-destination surveys, but a number of other sources were also utilized including the Nationwide Personal Transportation Study (1969),[1] the 1974 National Transportation Study,[2] the Federal Highway Administration's publication Highway Statistics[3] and others.

The design of the hybrid vehicle is to be based on specific vehicle uses or "missions." Previous examination of the travel data has lead to the division of drivers into three groups with widely differing travel patterns: primary, secondary, and only drivers, No other groups of drivers were clearly distinguisable on the basis of their reported travel. Primary and secondary drivers are from multi-car, multi-driver households, where the primary driver is defined as the driver who travels the greatest distance each day. Secondary drivers are the other drivers at multi-driver households. The only driver is from a one-car, one-driver household. Drivers sharing a car were not included in the data processed. Drivers in each of these classes use their cars differently and require different capabilities of their vehicles; that is each driver class performs a different "mission". Wherever possible, the travel data in this report has been split out by these three driver classes. It is interesting to note that the data for the only driver class is very close to the average for all drivers taken together. Information on another specific vehicle use, taxis, is also included in a separate section.

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[1] Nationwide Personal Transportation Study, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., April 1972.

[2] 1974 National Transportation Study, U.S. Department of Transportation, Washington, D.C., February 1975.

[3] Highway Statistics, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., Annual.

In addition to data on vehicle travel, this report also contains information on cargo capacity, availability of off-street parking (as required for battery recharging) and accident involvement rates based on the acceleration and gradeability capability of the hybrid vehicle.

2 DISTRIBUTIONS OF DAILY TRAVEL

2.1 TRAVEL LESS THAN SPECIFIED RANGE

Daily travel data were derived from the Los Angeles and Washington, D.C. origin-destination surveys. Distributions of reported driving distance for the three driver groups are shown in Table 2.1. The columns contain cumulative percentages, with the left-hand figure representing Los Angeles data, the right, Washington, D.C. Each distribution is displayed graphically in Figs. 2.1-2.3 with the lower edge of each band corresponding to the Los Angeles data points. The Los Angeles and Washington data do not show the length of trips beginning or ending outside the urban area. Thus, Table 2.1 and Figs. 2.1-2.3 apply only to urban driving. Roughly, one percent of all trips reported on the survey day began or ended outside the survey areas. The data do not account for long distance travel, such as vacation trips, made by 63 percent of households. A GRC report[1] has estimated that 35 percent of personal cars take round trips in excess of 320 km. Also the distributions cannot be applied to rural drivers who tend to drive greater distances than urban drivers.

The distributions were developed from information on individual trips during the survey day; therefore the data refer to the distribution of a number of drivers on a single day. If the assumption is made that the drivers form a homogeneous group (checks within each driver groups revealed no significant differences), the data also give the distribution of travel by an individual driver over many days.

Column set A shows the distributions of travel reported by drivers on the survey days. In Washington, the travel per driver was considerably less than in Los Angeles, and the difference is greater at the longer ranges as might be expected from the smaller size of the Washington region, which limits the opportunities for long urban trips in a single day. The average daily distance per driver is 50 km for Los Angeles and 33 km for Washington, D.C.

[1] M.M. Collins, Automobile and Light Truck Range Requirements (draft), General Research Corporation IM-2193, December 1978.

TABLE 2.1

DISTRIBUTIONS OF DAILY TRAVEL VERSUS DISTANCE IN

LOS ANGELES AND WASHINGTON, D.C.

Driving Distance, km	A: Percent of Drivers Reporting Less Than Specified Driving Distance			B: Percent of Total Driving Distance By Drivers Reporting Less Than Specified Driving Distance			C: Percent of Total Driving Distance Less Than Specified Driving Distance		
	Secondary	Only	Primary	Secondary	Only	Primary	Secondary	Only	Primary
10	23.5-32.1	17.0-20.3	3.3-5.3	4.9-7.9	2.0-3.3	0.3-0.7	32.2-41.0	19.7-23.1	12.7-20.4
20	49.6-59.3	35.4-41.4	11.5-16.3	18.7-27.5	7.9-13.2	1.9-4.2	54.7-67.2	35.4-49.5	24.6-33.0
30	67.2-77.8	50.5-59.4	21.8-33.3	34.2-49.8	15.9-27.0	5.2-13.0	69.3-82.3	47.5-64.8	35.3-54.7
40	78.1-87.9	61.0-72.7	32.5-49.4	47.7-66.9	23.7-41.4	10.0-24.7	79.0-90.5	56.9-75.2	44.6-66.9
50	85.4-93.3	69.5-80.9	42.8-63.4	59.4-78.7	31.8-52.8	15.9-37.8	85.5-95.0	64.2-82.5	52.6-76.0
60	90.3-96.6	75.7-86.8	51.7-74.0	69.0-87.5	39.1-62.8	22.2-49.9	89.8-97.4	70.1-87.4	59.4-82.4
70	93.6-98.4	79.9-91.1	59.5-81.5	76.6-93.1	44.9-71.5	28.6-60.0	92.6-98.6	74.8-90.8	64.9-87.0
80	95.6-99.0	83.9-93.9	65.8-86.7	82.0-95.3	51.3-78.0	34.7-68.2	94.6-99.2	78.7-93.2	69.8-90.3
90	96.9-99.6	86.9-95.7	71.1-90.7	85.9-97.8	56.7-82.7	40.5-75.2	95.9-99.6	81.8-94.7	73.8-92.7
100	97.6-99.8	89.4-96.9	75.5-93.2	88.3-98.7	61.7-86.3	45.8-80.2	96.9-99.7	84.3-95.9	77.2-94.4
120	98.7-99.9	92.4-98.3	82.1-96.2	92.6	68.7-91.0	55.1-87.0	98.2	88.1-97.3	82.6-96.5
140	99.3	94.3-98.9	86.6-97.8	95.4	73.9-93.4	62.6-91.3	98.9	90.9-98.1	86.7-97.7
160		95.9-99.2	89.4-98.4	96.5	79.0-94.7	67.9-93.1		93.0-98.7	89.6-98.5
180		96.7-99.6	91.8-99.0	97.6	81.8-96.8	73.1-95.3		94.4-99.1	92.0-99.0
200		97.4	93.7-99.4	99.0	84.7-97.4	77.8-96.8		95.8-99.3	94.0-99.3
220		98.1	95.2-99.6		87.8-98.1	81.8-97.7		96.7	95.4-99.5
240		98.6	96.2		90.3	84.8-98.2		97.4	96.5-99.7
260		98.8	97.2		95.4	88.0-98.7		97.7	97.3-99.8
280		99.1	97.8		96.5	90.0		98.3	97.9
300		99.2	98.4		97.6	92.3			98.5

Source: Los Angeles and Washington, D.C., Origin-Destination Surveys

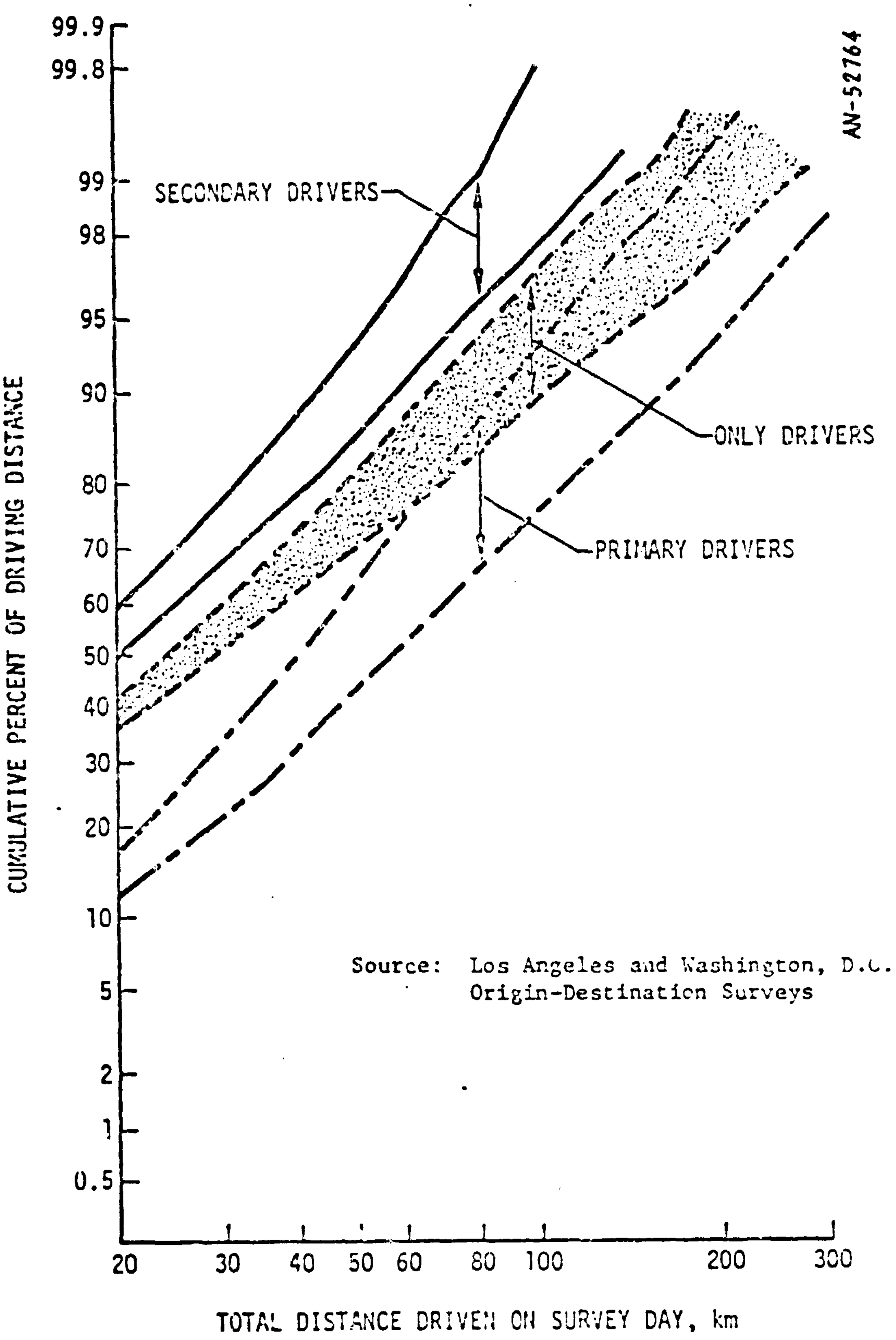


Figure 2.1. Percent of Drivers Reporting Less Than the Specified Driving Distance

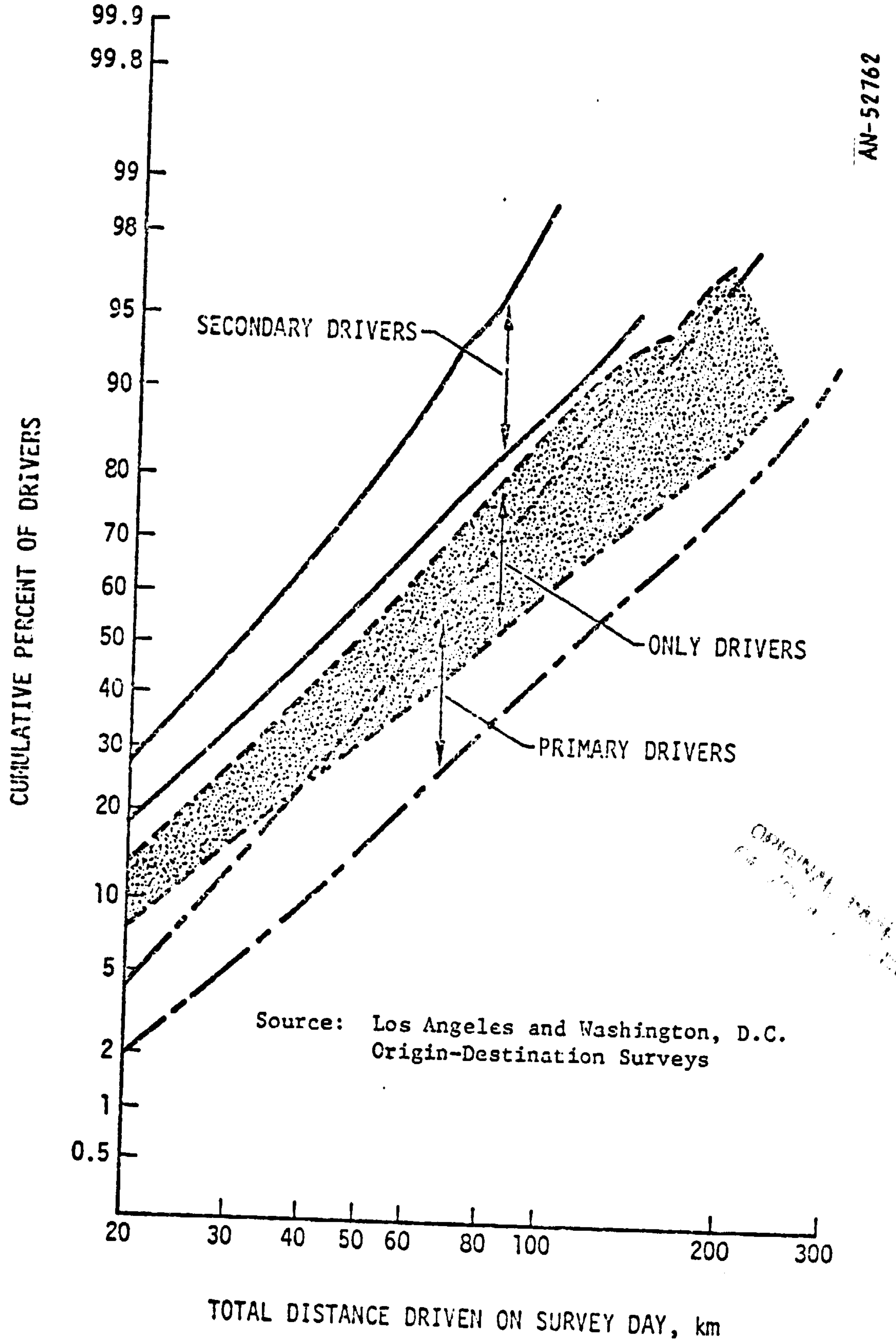


Figure 2.2. Percent of Driving Distance By Drivers Reporting Less Than Specified Driving Distance

C-2

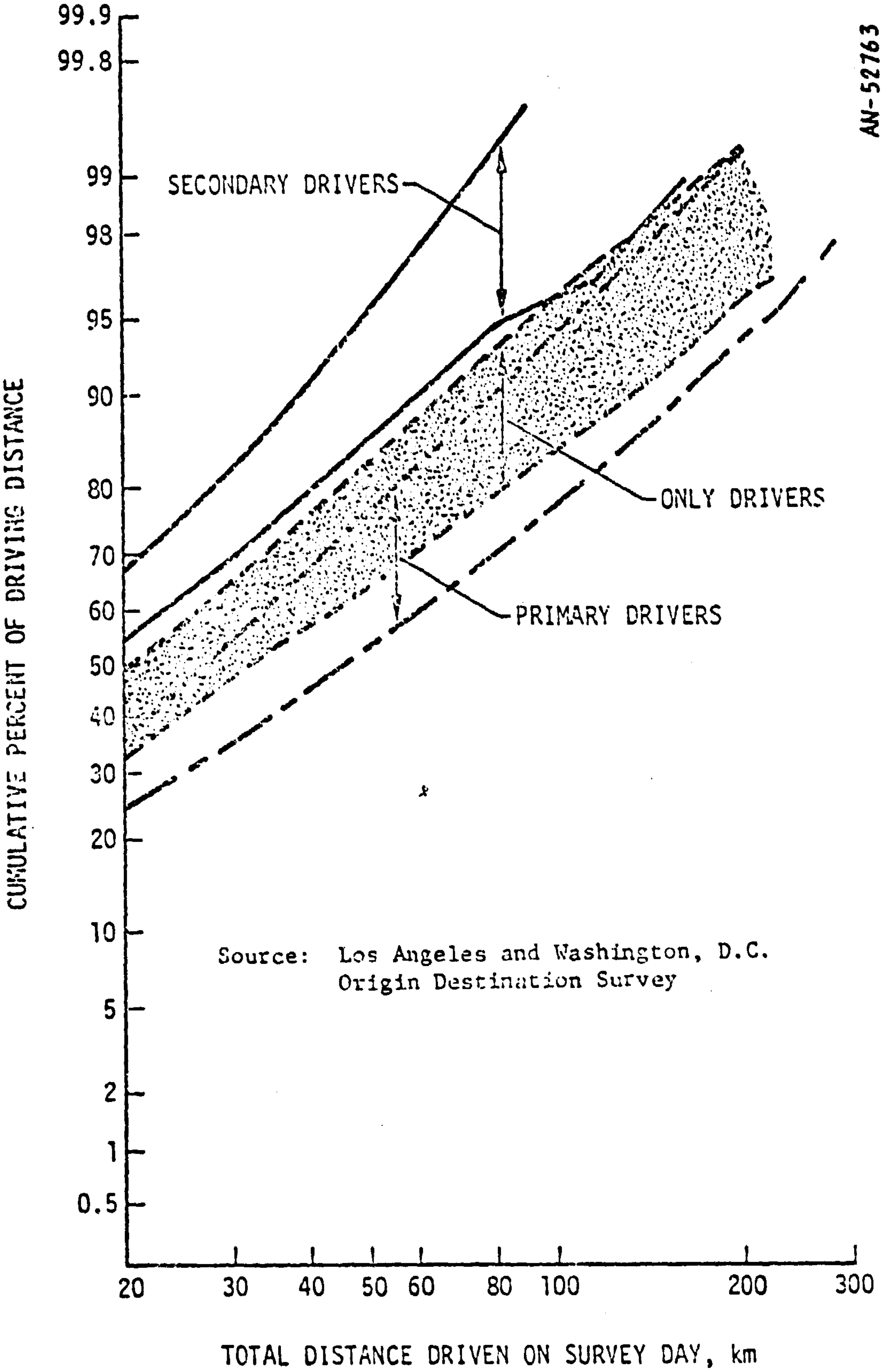


Figure 2.3. Percent of Total Driving Distance Less Than Specified Driving Distance

The second set of columns (B) shows the percent of total travel reported by drivers who drove less than a given distance. This data indicate the percentage of total driving distance which could be accomplished by range-limited (e.g., electric) cars. Even if a car of this range were useless on all other days requiring more travel, it could serve this percentage of total driving distance.

Column set C shows the percent of all driving within a specified range. This data indicates the percent of total driving distance which could be accomplished on an electric propulsion system of a given range in a hybrid car. The distribution assumes that the entire electric range is useful on every day requiring a longer total range.

Table 2.2 shows the average daily and annual ranges and the annual range of the 95th and 98th percentile dirvers in Los Angeles and Washington. When working with the assumption that the distributions of daily travel in Table 2.1 can be used to represent travel by one driver over many days, annual ranges cannot be directly calculated by multiplying the daily driving distance by 365. A 95th percentile driver on the survey day is expected to drive as far on only 5 percent of his driving days.

If we assume that each driver's travel is uncorrelated from day to day, the Central Limit Theorem says that the mean and variance of the annual travel will be 365 times the mean and variance of the daily travel.

The mean and variance of the daily travel can be calculated directly from the distributions in Table 2.1 using the technique shown in the appendix. Once the mean and variance of daily travel are known, the 95th and 98th percentile distances are found with the aid of standard normal (Gaussian) distribution tables. The 95th and 98th percentile points occur at 1.645σ and 2.054σ respectively, where σ is the standard deviation. For example,

TABLE 2.2

DAILY AND ANNUAL DRIVING DISTANCE

	Daily Driving, km			Annual Driving, km			
	Average Daily Range						
Type of Driver	Survey	Derived	Standard Deviation	Standard Deviation	Average	95th Percentile	98th Percentile
Secondary							
Los Angeles	27.9	27.7	25.1	480	10,100	10,887	11,083
Washington	20.5	20.6	17.3	331	7,534	8,076	8,211
Only							
Los Angeles	47.0	46.4	50.8	971	16,947	18,542	18,941
Washington	32.2	32.0	28.6	546	11,682	12,582	12,803
Primary							
Los Angeles	76.1	76.8	63.5	1,213	28,045	30,042	30,536
Washington	48.0	47.8	33.9	648	17,462	18,526	18,793

if the mean and variance of the daily travel distribution are 35 km and 800 km^2, then the mean and variance of the annual travel are 12,775 (= 365 × 35) km and 292,000 (= 365 × 800) km^2. The standard deviation of annual travel is only 540 km (= $292{,}000^{1/2}$) so the 95th and 98th percentile travel ranges are 13,664 km and 13,885 km.

Note that the above approach leads to a distribution of annual driving which is relatively narrow, i.e., the ratio of standard deviation to average is small. This occurs because the average increases as N while the standard deviation increases as $N^{1/2}$, where N is the number of days (365 in this case).

In Table 2.2 both the survey and derived daily ranges are included for comparison. Note that these ranges are essentially the same for each comparable case. This serves as a check on both the consistency of the tabular distributions and the method used to derive the mean (average) and variance of the daily driving distribution.

As mentioned earlier, the derived annual distributions are relatively narrow. The actual distributions are undoubtably wider for several reasons. One, the survey only recorded trips which were taken entirely within the survey area, thus excluding some long trips. Two, the survey may not have accurately sampled drivers who are constantly on the road for their livelihood, e.g., salesmen, truck drivers, etc. And three, the assumption that all drivers on the survey day give accurate statistics for a driver on all days may introduce appreciable errors at the extreme driving ranges.

A number of studies have collected data on the average distance traveled. Table 2.3 shows the average annual vehicle kilometers traveled per personal passenger vehicle as estimated by several sources. The overall average is about 16,000 kilometers per vehicle, and has remained reasonably constant throughout the years surveyed. The annual kilometers estimated from the Los Angeles and Washington, D.C. are within the range of estimates provided by other studies.

TABLE 2.3

PERSONAL PASSENGER VEHICLE ANNUAL TRAVEL

Source	Data Year	Annual Vehicle Kilometers Traveled
Los Angeles Origin-Destination Survey	1967	16,947
Washington, D.C. Origin-Destination Survey	1968	11,682
Nationwide Personal Transportation Study	1969	18,676
JPL Estimate for Hybrid Vehicle Study (Based on NPTS)	1975	17,466
Highway Statistics (FHWA)	1969	15,749
	1970	16,065
	1971	16,295
	1972	16,396
	1973	16,087
	1974	15,285
National Transportation Study	1972	
Large Cities (23)*		
Average		15,298
Range		11,011 - 20,983
Smaller Cities (23)†		
Average		17,555
Range		9,415 - 21,044

*Cities with 1972 population over one million.

†Cities with 1972 population between 250,000 and 500,000.

2.2 TRIP FREQUENCY AND AVERAGE TRIP DISTANCE

The distribution of the number of driver trips per day shown in Table 2.4 was developed from the Los Angeles and Washington, D.C. origin-destination surveys. The data indicate that the 95th percentile only drivers in Los Angeles average five more trips per day than Washington only drivers while covering 62 more kilometers (see Table 2.5). Dividing the daily range by the number of trips would indicate that the average trip distance in Washington, D.C. (11.3 km) is about the same as in Los Angeles (12.3 km).

The actual joint distribution of trip frequency and trip distance has not been calculated. Examination of the 10 percent of secondary drivers who make the longest trips reveals that they make both longer trips and more frequent trips per day.

The Nationwide Personal Transportation Study found that over half of daily trips are less than 8 kilometers long. Of the 23 large cities examined from the 1974 National Transportation Study, the average trip distance was 10.6 kilometers; in smaller cities the average was 8.2 kilometers.

2.3 FREEWAY TRAVEL

The data on the percent of urban travel on freeways, presented in Table 2.6 were obtained from the 1974 National Transportation Study. The information is from a previous GRC report[1] which processed data from 46 geographically distributed cities, 23 large cities with populations over one million (1972) and a like number of smaller cities with one-quarter to one-half million in population.

The overall city average puts the portion of travel on freeways at about 28 percent; but the range is quite large, varying from less than

[1] M. M. Collins and L. Morecraft, Applicability of Existing Regional Data to National Impact Analysis for Urban Electric Cars, General Research Corporation IM-2045, June 1976.

TABLE 2.4

DISTRIBUTIONS OF DRIVER TRIPS PER DAY

Trips per Day	Secondary		Only		Primary	
	Los Angeles	Washington	Los Angeles	Washington	Los Angeles	Washington
1	1.9	3.2	1.5	2.8	0.9	1.0
2	40.9	63.9	36.2	55.9	26.5	43.7
3	51.8	68.9	44.5	61.7	31.7	48.6
4	65.1	87.8	58.6	83.2	45.8	73.0
5	75.4	90.0	69.5	85.8	55.3	76.7
6	81.1	95.6	76.8	92.8	63.4	86.8
7	86.4	96.3	82.1	94.2	70.8	88.9
8	89.9	98.2	86.7	96.7	76.1	93.3
9	92.5	98.5	89.4	97.3	80.5	94.5
10	94.5	99.3	92.3	98.3	84.7	96.2
11	95.8		93.9	98.7	87.2	96.6
12	96.8		95.3	99.1	89.6	97.6
13	97.7		96.4		91.8	98.0
14	98.3		97.2		93.4	98.6
15	98.9		97.7		94.3	98.9
16	99.1		98.2		95.3	99.1
17			98.5		96.1	
18			98.8		96.9	
19			99.1		97.4	
20					97.9	
21					98.2	
22					98.6	
23					98.8	
24					98.9	
25					99.1	

Source: Los Angeles and Washington, D.C. Origin-Destination Survey

TABLE 2.5

DAILY RANGE AND TRIPS PER DAY

	Daily Range		Trips per Day	
	95th Percentile, km	98th Percentile, km	95th Percentile	98th Percentile
Secondary Drivers				
Los Angeles	77	105	10	14
Washington	54	67	6	8
Only Drivers				
Los Angeles	147	218	12	16
Washington	85	113	7	10
Primary Drivers				
Los Angeles	218	285	16	20
Washington	110	145	9	13

Source: Los Angeles and Washington, D.C. Origin-Destination Surveys

TABLE 2.6

PERCENT OF TRAVEL ON FREEWAYS

	Percent Freeway Travel
Los Angeles	38.6
Washington, D.C.	38.2
Large City Average	33.5
Small City Average	23.1
Total Average (46 cities)	28.3
Range	7.4 - 54.2

Source: FHWA's 1974 National Transportation Study

10 to over 50 percent freeway driving. As might be expected, smaller cities, which would have less developed highway systems, show about 10 percent less freeway driving than the large cities. The data point for Washington, D.C. seems suspiciously high, since the only major freeway system at the time was the Beltway which encircles the city, but the 39 percent freeway travel in Los Angeles agrees well with other data sources.

2.4 TRAVEL SPEED

The average travel speeds on freeways and surface streets shown in Table 2.7 were gathered from the 1974 National Transportation Study. Average speeds are higher in smaller cities, most likely a reflection of traffic density. The travel speeds are taken to be the 24 hour average moving speed attained on the roadway, as the speeds here are considerably higher than other estimates obtained by dividing trip distances by trip times, which would include time stopped at intersections, etc. (as do the SAE and Federal driving cycles). These data were collected prior to the 1974 imposition of the 55 mph speed limit; present speeds would be expected to be slightly lower for freeway driving.

The 1974 Highway Statistics contains data on the average speed of passenger cars on urban primary and secondary roads and suburban primary roads. These data show lower speeds on primary roads reflecting the imposition of the 55 mph speed limit. Data on median time and median distance to work for various cities are shown in Fig. 2.4. As would be expected, workers in smaller cities travel shorter distances to their place of employment and workers in larger cities spend a greater amount of time commuting. Of the 41 cities surveys[1], the great majority lie between the 30 km/hr and 40 km/hr lines in Fig. 2.4. This would be a good indication of the average speeds attained during the peak traffic hours.

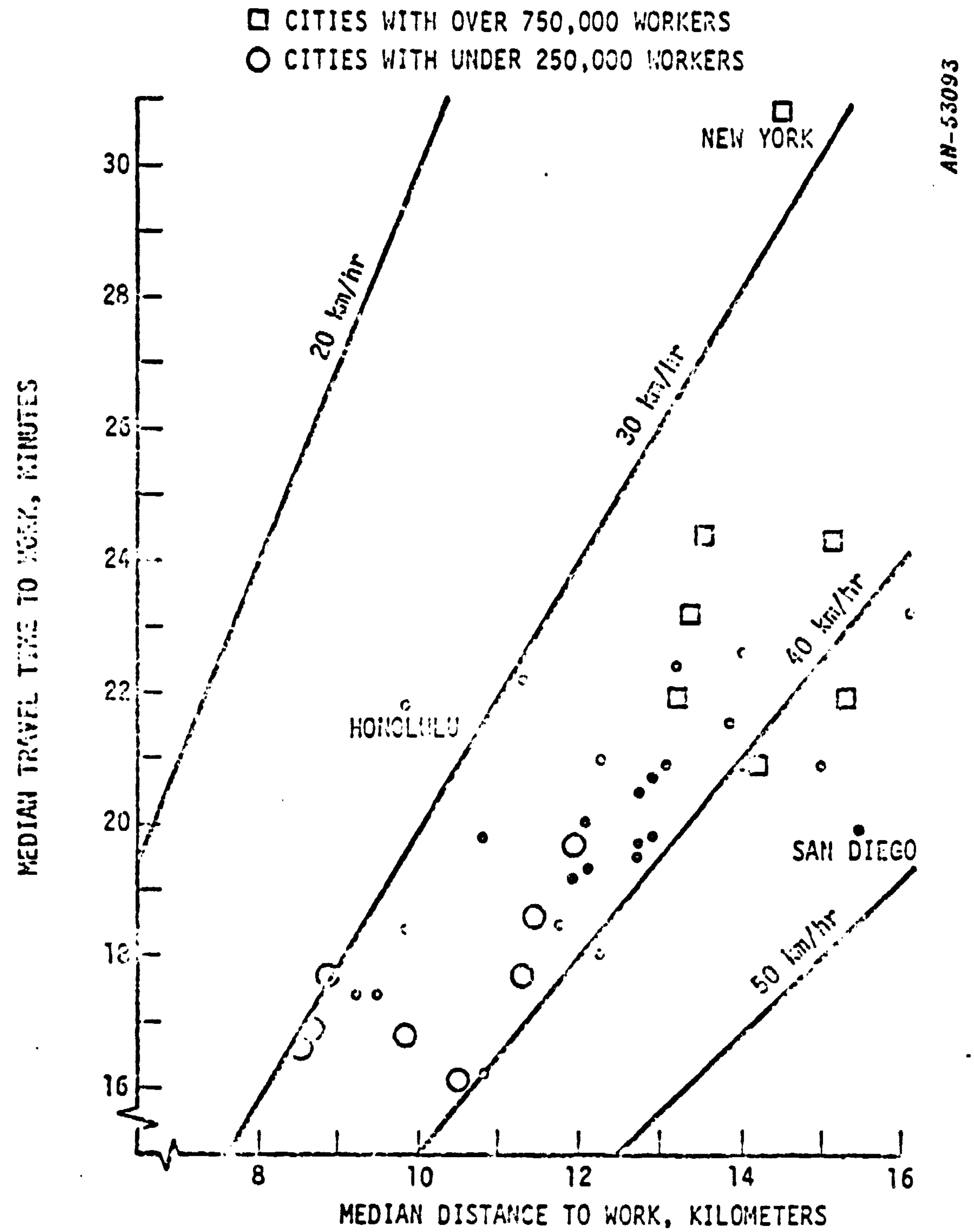
[1] Selected Characteristics of Travel to Work in 20 Metropolitan Areas: 1975 and 1976, U.S. Department of Commerce, Bureau of the Census, Series P-23, No. 68, February 1978 and Series P-23, No. 72, September 1978.

TABLE 2.7

AVERAGE SPEED

	Freeway, km/hr	Surface Street, km/hr
National Transportation Study Data (1972):		
Los Angeles	88.6	46.7
Washington, D.C.	86.9	48.3
Large City Average	81.2	43.6
Smaller City Average	86.9	47.7
Total Average (46 cities)	84.1	45.6
Range	61 - 106	32 - 69

	Average Speed of Passenger Cars, km/hr
1974 Highway Statistics Data:	
Urban Primary Roads	68.4
Urban Secondary Roads	52.2
Suburban Primary Roads	77.1



Source: Census Bureau's Selected Characteristics of Travel to Work in 20 Metropolitan Areas 1975 and 1976.

Figure 2.4. Median Travel Time for Work Travel in a Vehicle

3 CHARACTERISTICS OF VEHICLE USE

3.1 TRIP PURPOSE

The best information available on this purpose is from the 1969 Nationwide Personal Transportation Study. These data have already been compiled in the JPL Hybrid Vehicle Potential Assessment[1] report. Rather than complicate the issue with data from other, less complete sources, the JPL table is reproduced in Table 3.1.

Work trips are the major recurring class of trips accounting for 36 percent of all trips and 42 percent of vehicle travel annually. Social and recreational trips are shorter and less frequent (22 percent of trips) than other trips but still account for a third of the distance traveled each year.

3.2 VEHICLE OCCUPANCY

The number of vehicle occupants (driver plus passengers) noted in the Los Angeles and Washington studies is presented in Table 3.2. According to these data, the passenger requirements of over 95 percent of trips could be fulfilled by a four-seated car. A five-passenger car which would satisfy the space needed for about 98 percent of all trips. The JPL study[1] includes vehicle occupancy data broken out by trip purpose. This information from the Nationwide Personal Transportation Study is reproduced in Table 3.3.

3.3 CARGO PAYLOAD

The trunk or cargo space figures for all car models (excluding station wagons and two-seaters) were taken from the EPA's 1978 California Gas Mileage Guide.[2] Table 3.4 shows the average cargo space along with the range of trunk sizes available in each car class. The

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[1] F. Surber, Hybrid Vehicle Potential Assessment, Interim Progress Report, Draft, Jet Propulsion Laboratory 5030-162, Pasadena, California, February 1978.

[2] 1978 Gas Mileage Guide, California, U.S. Department of Energy, U.S. Environmental Protection Agency, Washington, D.C. February 1978.

TABLE 3.1

HOUSEHOLD TRAVEL DISTRIBUTION BY TRIP PURPOSE

Source: JPL's Hybrid Vehicle Potential Assessment

Trip Purpose	Percent of automobiles		Trip length	Trip rate per household		Vehicle-Kilometers per household	
	Trips	Travel	(km)	Annual	Daily	Annual	Daily
Earn a living							
Home-to-work	31.9	33.7	15.0	445	1.2	6693	18.4
Related business	4.3	7.9	25.8	61	0.2	1573	4.3
Subtotal	36.2	41.6	16.3	506	1.4	8265	22.7
Family business							
Shopping	15.2	7.5	7.0	213	0.6	1486	4.2
Medical and dental	1.8	1.6	13.4	24	0.1	323	0.8
Other	14.0	10.2	10.4	185	0.5	2032	5.6
Subtotal	31.0	19.3	9.0	422	1.2	3841	10.6
Civic, educational and religious	9.3	4.9	7.5	130	0.4	979	2.6
Social and recreational							
Visiting friends and relatives	8.9	12.1	19.2	125	0.3	2395	6.6
Pleasure driving	1.4	3.1	30.2	13	0.1	610	1.6
Vacations	0.1	2.5	256.0	2	0.05	512	1.4
Other	12.0	15.3	18.2	166	0.4	3034	8.3
Subtotal	22.4	33.0	21.0	312	0.8	6552	17.9
Other and unknown	1.1	1.2	15.0	16	(2)	240	0.6
Total	100.0	100.0		1396	3.2	19878	54.4

TABLE 3.2

VEHICLE OCCUPANCY

Percent Carrying at Most N Passengers (including driver)	Driver Class					
	Secondary		Only		Primary	
	Los Angeles	Washington	Los Angeles	Washington	Los Angeles	Washington
N = 1	66.2	67.9	66.1	68.1	52.9	58.1
N = 2	84.1	85.6	86.2	88.9	79.1	83.8
N = 3	92.4	93.7	94.4	95.3	89.0	92.1
N = 4	96.8	97.3	97.5	98.3	95.3	96.6
N = 5	98.6	98.8	99.0	99.2	97.8	98.6
N = 6	99.3	99.6	99.5	99.7	99.0	99.5

Source: Los Angeles and Washington, D.C. Origin-Destination Surveys

TABLE 3.3

DISTRIBUTION OF AUTOMOBILE TRIPS BY NUMBER OF OCCUPANTS FOR EACH PURPOSE OF TRAVEL – RESIDENTS OF STANDARD METROPOLITAN STATISTICAL AREAS

Source: JPL's Hybrid Vehicle Potential Assessment

Number of occupants	Major purpose of trip: Earning a living			Family business				Educational, civic, and religious	Social and Recreational					All purposes
	To and from work	Related business	Total	Medical and dental	Shopping	Other	Total		Vacation	Visits to friends or relatives	Pleasure rides	Other	Total	
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent*	Percent	Percent	Percent	Percent	Percent
1	74.5	62.9	73.2	35.5	43.7	45.9	44.4	33.7	*	36.3	17.0	27.3	30.1	50.9
2	17.6	24.7	18.4	33.2	34.0	31.2	33.0	25.5	*	31.4	41.1	36.0	34.5	27.3
3	4.1	7.5	4.5	12.5	11.5	12.5	12.0	15.8	*	14.0	13.2	12.7	13.6	9.9
4	1.6	2.6	1.8	4.2	6.1	4.7	5.4	10.3	*	8.9	16.2	11.2	10.6	5.7
5	1.0	0.8	1.0	2.2	2.5	3.1	2.7	5.5	*	4.1	7.8	5.2	5.1	2.9
6	0.4	0.5	0.4	3.7	0.8	1.3	1.1	3.6	*	2.2	2.0	4.0	3.2	1.5
7	0.1	--	--	0.3	0.8	0.6	0.7	1.6	*	1.3	2.5	1.5	1.5	0.7
8	0.1	0.1	0.1	--	--	--	--	0.6	*	0.3	--	0.6	0.4	0.2
9 or more	--	0.3	--	--	0.3	0.1	0.2	0.5	*	0.3	--	1.0	0.5	0.3
N/A	0.6	0.6	0.6	0.3	0.3	0.6	0.5	1.4		0.4	0.2	0.5	0.5	0.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total number (000) of daily trips	53,033	6,716	59,749	2,755	25,937	21,407	50,099	24,844	244	14,068	2,036	20,088	36,435	163,964

* Available data not sufficient for analysis

SOURCE: Based upon unpublished table P-8 from the Nationwide Personal Transportation Survey conducted by the Bureau of the Census for Federal Highway Administration, 1969-1970.

larger spaces are associated with hatchback models. Weighting the average cargo space by the sales in each class yields an average cargo space of 0.44 m^3 for cars sold. The 95th percentile space is 0.62 m^3, the 98th percentile is 0.65 m^3. These statistics do not necessarily represent the desired cargo space, since this dimension is only one of many features figuring into the car-buying decision

TABLE 3.4

CARGO SPACE AVAILABLE

1978 MODEL CARS*

	Average Space, m^3	Space Range, m^3
Subcompacts	0.28	0.14 - 0.51
Compacts	0.40	0.28 - 0.59
Mid-sized	0.46	0.40 - 0.57
Large-sized	0.58	0.48 - 0.65

Sales Weighted Average	0.44 m^3
95th Percentile Cargo Space	0.62 m^3
98th Percentile Cargo Space	0.65 m^3

*Station wagon and two-seater model excluded.

Source: EPA's 1978 Gas Mileage Guide, California

4 VEHICLE LOCATION

The figures in this section have been estimated from data collected in the Census Bureau's Annual Housing Survey.[1] The survey questionnaire asked for the number of cars available to the household, but does not define the term "available". Presumably "available" would include not only cars owned by and registered to the household members, but also leased, rented, and borrowed cars and company or fleet cars available for personal use.

The automobile data are split into those at one-car households and those at multi-car households. This division does not exactly match the breakout of driver classes (i.e., only drivers and primary/secondary drivers) because the origin-destination survey data reported here excluded households where drivers shared a car. Therefore, the number of one-car households is greater than the number of only drivers, since one-car households with more than one driver were eliminated from the data. Yet reasonable estimates can be obtained by ignoring this distinction because of the low occurrence of vehicle sharing. In Los Angeles, only 12 percent of drivers reporting trips came from households where sharing a vehicle was necessary. In Washington, only 9 percent of drivers shared a car. These percentages will decline in the future; as automobile ownership continues to rise; nearly every driver will have his own car.

In this section, the term "Urban area" refers to Standard Metropolitan Statistical Areas (SMSAs), each of which consist of a county or group of counties that contain one or more central cities with populations over 50,000.

4.1 AVAILABILITY OF CARS WITH OFF-STREET PARKING

Since off-street parking is required for residential recharging, it is necessary next to estimate the number of cars available with

[1] Annual Housing Survey, U.S. Department of Commerce, Bureau of the Census, and U.S. Department of Housing and Urban Development, Washington, D.C., Annual.

off-street parking. The estimates must also distinguish between cars at single-family units and at multi-family units, where recharging facilities may be more difficult to obtain, and between cars serving the three major classes of drivers: secondary, primary, and only drivers. Recently-published reports of the Annual Housing Survey summarize this information for owner- and renter-occupied units, together with the availability of cars at these units.

All housing units in Survey reports are broken down according to whether they are occupied by owners or renters. Furthermore, detailed tabulations are available only for certain specific types of housing units. "Specified owner-occupied" units are owner-occupied single-family homes on ten acres or less, with no business on the property. "Specified-renter-occupied" units include most renter-occupied units, but exclude single-family renter-occupied units on ten acres or more.

As Table 4.1 indicates, these two classes of occupied units amount to substantially less than the national total—about 15 percent less. The remaining units are largely rural single-family rentals, single-family owner-occupied homes on ten acres or more, or with a business on the property, and owner-occupied multi-family housing units. To include the units omitted in the two classes for which parking availability is published, it is necessary to extrapolate from Table 4.1. The results of such an extrapolation are summarized in Table 4.2.

The extrapolation was made in three steps. First, specified renter-occupied housing units were simply scaled up, assuming that the added units were like those tabulated, to give totals for all renter-occupied housing units. The necessary scaling factor is very near unity for this step. Second, single-family units which were renter-occupied were subtracted from the renter categories and added to specified owner-occupied units to approximate all single-family housing units. For this step, the single-family renter-occupied units were assumed to have the same numbers of cars per unit, and the same availability of off-street parking, as the specified renter-occupied units. This tends to

TABLE 4.1

REPORTED AVAILABILITY OF CARS AND OFF-STREET PARKING, 1974

	Housing Units, thousands	Percent Units with:				Cars Available		Units with Parking, percent
		No Car	1 Car	2 Cars	3 or More Cars	Total, thousands	Per Unit	
All Occupied Housing Units	70,830	17	48	28	7	88,197	1.25	-*
Specified Owner-Occupied**	36,154	8	45	37	10	53,681	1.48	75†
Specified Renter-Occupied††	24,292	31	50	17	2	22,065	.91	91§
Occupied Units in SMSAs	48,674	18	46	30	7	61,129	1.26	-
Specified Owner-Occupied	25,057	8	42	40	10	38,637	1.54	77
Specified Renter-Occupied	18,800	32	49	17	2	16,710	.89	92
Occupied Units Outside SMSAs	22,156	15	54	25	6	27,070	1.22	-
Specified Owner-Occupied	11,097	11	51	30	8	15,042	1.36	69
Specified Renter-Occupied	5,491	25	54	18	2	5,355	.98	87

*Not tabulated

**Includes only one-family homes on ten acres or less with no business on property

†With garage or carport on property

††Excludes one-family homes on ten acres or more

§Off-street parking facilities included in rent

Source: US Bureau of the Census, Annual Housing Survey: 1974, Parts A and C

TABLE 4.2

ESTIMATED AVAILABILITY OF CARS AND OFF-STREET PARKING

	United States	Outside SMSAs	In SMSAs: Total	In SMSAs: In Central Cities	In SMSAs: Outside Central Cities	Los Angeles Long Beach SMSA	Washington DC SMSA
Population, thousands	211,391	56,427	154,964	-	-	6,926	3,015
Occupied Housing Units, thousands	70,830	19,586	48,674	22,566	26,109	2,520	981
With Parking, percent	83	77	85	86	84	94	71
Single Family, percent	63	75	61	52	70	61	56
With Parking, percent	78	73	80	80	79	94	54
Multifamily, percent	37	25	39	48	30	39	44
With Parking, percent	91	87	92	93	91	94	93
Persons Per Unit	2.98	2.88	3.18			2.75	3.07
Cars Available (estimate), thousands	85,178	23,321	59,628	23,278	36,778	3,243	1,302
Percent of US Total	100	27	70	27	43	4.6	1.5
Cars Per Occupied Housing Unit	1.20	1.19	1.23	1.03	1.41	1.28	1.33
Cars as Percent of Available Cars							
At 1 Car Units	39.4	44.1	36.9	43.7	32.5	37.1	32.1
Single-Family	24.0	32.9	21.5	22.7	20.8	20.4	14.9
Multi-Family	15.4	11.2	15.4	21.1	11.8	16.7	17.2
At 2 Car Units	45.6	42.2	47.3	43.0	50.2	45.9	43.0
Single-Family	35.0	34.5	36.7	31.5	39.9	34.1	35.3
Multi-Family	10.5	7.5	10.6	11.4	10.3	11.8	12.7
At 3 or More Car Units	15.1	14.0	15.8	13.3	17.3	17.0	19.9
Single-Family	13.0	12.5	13.7	11.1	15.3	14.5	16.9
Multi-Family	2.1	1.5	2.1	2.2	2.0	2.5	3.0
Cars with Parking, percent*	56-83	65-77	52-85	62-86	58-84	67-92	47-71

*Assumes each housing unit with parking has either 1 space (lower limit) or as many spaces as cars available (upper limit).

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u timate the number of cars, but to overestimate the availability o ing, since rented single-family units probably have more cars and l off-street parking than multi-family units. Third, the renter-upied housing units found in the first step were scaled up to include owner-occupied multi-family housing units. The owner-occupied units were assumed to have the same auto availability and parking availability as specified renter-occupied units, again a conservative assumption.

The results of this expansion are shown in Table 4.2 for various geographic breakdowns, including single SMSAs which constitute major parts of the survey regions for Los Angeles and Washington. The estimate of cars available at all occupied units in Table 4.2 is about 3-1/2 percent below that reported in the Annual Housing Survey. For cars available in SMSAs, however, the underestimate is less: only 2-1/2 percent. These underestimates appear insignificant relative to other uncertainties involved in using the data.

The principal uncertainty is in the meaning of "units with parking" in Tables 4.1 and 4.2. For single-family units, the Annual Housing Survey asked whether there was a garage or carport on the property. It did not determine the availability of other off-street parking, which might be in yards or driveways. At multi-family units, the Survey determined only whether parking facilities were included in the rent. The availability of other facilities, or the nature and location of facilities included in the rent, were not reported.

The figures for units with parking in Tables 4.1 and 4.2 are thus far from definitive. They do not show yard or driveway parking which may be available at single-family units, and they do not show the number of off-street parking spaces available per unit, at either single-family or multi-family housing units. No better figures, however, were located for use in this analysis.

The lower portion of Table 4.2 shows the percentage of the total cars in each column which are at one-car, two-car, and three-car housing units. It also shows percentages at single- and multi-family housing units, so they may be combined directly with the percentages of these types of units having off-street parking.

It is especially noteworthy in Table 4.2 that in Washington, D.C., only 54 percent of the single-family units had a garage or carport. This is much less than in Los Angeles, where 94 percent reported having a garage or carport, or in the United States as a whole, where 78 percent reported having a garage or carport. The implication is that the applicability of hybrid c[illegible] may be much less in areas like Washington than in auto-oriented r[illegible]as like Los Angeles.

It is also possible that single-family units in Washington frequently provide off-street parking in yards and driveways rather than in garages or carports. Unfortunately, the Washington origin-destination survey (unlike the Los Angeles survey) did not record the availability of off-street parking at residences, and an effort to locate other relevant descriptive data was unsuccessful.

Tables 4.3 and 4.4 correlate parking and auto availability with the house value or gross rent of the housing unit. The house value (for specified owner-occupied housing) and the gross rent (for specified renter-occupied housing) are used as proxy variables for household income, with which they are positively correlated. The data source (1974 Annual Housing Survey) did not list parking and auto availability by household income, but the median household income is given for each house value and group rent division. These data have been taken directly from the Survey and have not been adjusted as have the data in Table 4.2.

The data show the expected result of auto availability increasing with household income. The higher the value of specified owner-occupied houses, the more likely the house has a garage or carport. The vast majority of rented units have parking includes, regardless of the monthly rent.

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TABLE 4.3

PARKING AND AUTO AVAILABILITY BY VALUE OF HOUSE SPECIFIED OWNER OCCUPIED HOUSING

	House Value (dollars)							
Total U.S. Owner Households	Under $5000	$5000-$9999	$10,000-$14,999	$15,000-$19,999	$20,000-$24,999	$25,000-$34,999	$35,000 & Over	Total
Median Income (dollars)	4000	6100	8700	10,800	12,200	14,500	20,300	13,600
Units in Category (percent)	2	6	10	13	14	25	31	
Units with Garage/Carport (percent)	27	41	53	63	76	80	87	75
Automobiles Available (percent)								
No Car Households	39	45	17	10	7	5	2	6
One Car Households	46	55	53	55	62	46	33	45
Multi-Car Households	15	20	30	35	45	50	65	47
Urban Owner Households								
Inside SMSAs[a]								
Median Income	4200	6600	9100	11,300	12,500	14,900	20,800	14,800
Percent of Units in Category	1	4	9	11	14	27	36	
Units with Garage/Carport (percent)	25	40	57	69	77	81	87	77
Automobiles Available (percent)								
No Car Households	43	24	15	11	8	5	2	7
One Car Households	43	55	50	52	49	44	31	42
Multi-Car Households	14	21	31	37	43	51	67	51
Inside Central Cities								
Median Income	4300	6100	9100	11,300	12,400	15,200	20,500	13,500
Percent of Units in Category	1	6	12	15	15	25	24	
Units with Garage/Carport (percent)	24	40	53	69	72	84	83	75
Automobiles Available (percent)								
No Car Households	37	28	19	12	10	6	4	10
One Car Households	50	54	49	52	50	45	33	45
Multi-Car Households	13	18	31	35	40	49	63	45

[a]Includes households in central cities.

Source: U.S. Bureau of the Census, Annual Housing Survey 1974.

TABLE 4.4

PARKING AND AUTO AVAILABILITY BY GROSS RENT SPECIFIED RENTER OCCUPIED HOUSING

	Gross Monthly Rent (dollars)							
Total U.S. Renter-Occupied Households	No Cash Rent	Under 50	50-69	70-99	100-149	150-199	200 and Over	Total
Median Income, dollars	5,800	3,200	3,500	5,200	6,500	9,700	13,400	7,800
Units in Category (percent)	5	5	6	13	23	25	19	100
Units with Parking Included in Rent (percent)	—	98	98	97	95	96	92	96
Automobiles Available (percent)								
No Car Households	28	71	59	42	32	21	16	31
One Car Households	49	25	35	47	45	56	51	50
Multi-Car Households	22	4	6	10	23	23	33	19
Urban Renter-Occupied Households								
Inside SMSAs*								
Median Income, dollars	6,200	3,000	3,500	4,900	6,500	9,700	13,400	8,100
Percent of Units in Category	3	4	5	11	27	28	22	100
Units with Parking Included in Rent (percent)	—	99	98	96	96	95	92	95
Automobiles Available (percent)								
No Car Households	31	77	67	48	35	23	17	32
One Car Households	48	21	29	46	50	55	51	49
Multi-Car Households	22	2	4	6	15	22	32	19
Inside Central Cities								
Median Income, dollars	5,000	3,000	3,400	4,700	6,400	9,400	13,100	7,200
Percent of Units in Category	2	4	6	14	31	26	17	100
Units With Parking Included in Rent (percent)	—	96	98	95	96	95	90	93
Automobiles Available (percent)								
No Car Households	35	82	72	53	42	30	27	41
One Car Households	47	16	26	42	47	52	48	45
Multi-Car Households	17	1	2	6	11	18	25	14

*Includes households in central cities.

Source: U.S. Bureau of the Census, Annual Housing Survey 1974.

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4.2 URBAN-BASED CARS

Table 4.5 shows the percent of cars available to households located in urban areas. The urban areas (i.e., in SMSAs) are broken down into central cities and the remainder of the counties outside the incorporated limits of the central cities. This breakout is intended to estimate urban and suburban regions. The areas outside the SMSAs may be considered rural. Approximately 3 percent of private cars are not accounted for in this table.

One-car households are about evenly distributed between urban, suburban, and rural areas, while nearly half the cars in multi-car households are located in suburban regions.

TABLE 4.5

URBAN BASED CARS

Source: U.S. Bureau of Census' *Annual Housing Survey*

	Urban			
	Total Inside SMSAs	Inside Central Cities	Outside Central Cities	Rural Outside SMSAs
At One-Car Households	25.8	11.8	14.0	11.9
At Multi-Car Households	44.2	15.2	29.0	15.2

The applicability of cars requiring electric recharging as of 1974 may be simply estimated from the auto and parking availability data in the above tables. Table 4.6 breaks down cars available at residences according to their location (urban or rural), their function (secondary, only, or primary car), and the type of unit at which they are parked. The table shows a range of values for each entry, corresponding to cars at units with parking available and cars at all units. Only cars are, of course, those at one-car households in Table 4.2; primary cars are the first cars at two- and three-car households; and secondary cars are all other cars.

TABLE 4.6

AVAILABILITY OF CARS BY FUNCTION, 1974

Source: U.S. Bureau of Census' *Annual Housing Survey*

	Percent Urban Cars*		Percent Non-Urban Cars**	
	At Single-Family Units	At Multi-Family Units	At Single-Family Units	At Multi-Family Units
Secondary Cars	22-28†	6.2-6.7††	19-26†	4.1-4.8††
Only Cars	17-22	14-15	24-[illegible]	10-11
Primary Cars	18-23	5.5-6.0	[illegible]	3.7-4.[illegible]

*In SMSAs

**Not in SMSAs

†First figure only includes cars at units with garage or carport. Second figure includes cars at units without garage or carport.

††First figure only includes cars at units with off-street parking included in rent. Second figure includes cars at units without off-street parking included in rent.

5 ACCIDENT RATES

Accident rates on grades and at freeway access points (frequently uphill in urban areas) are closely correlated with the speed differential between involved vehicles.[1] This section estimates accident frequency as a function of acceleration capability and percent road grade.

Gradeability has been calculated for a car with sufficient power to meet the most strenuous minimum acceleration specification (0-90 km/hr in 15 seconds) required by JPL for the hybrid vehicle. (This power is also sufficient to meet all the minimum gradeability specifications.) Figure 5.1 plots velocity versus percent grade for a typical hybrid vehicle with the specifications shown in Table 5.1.

TABLE 5.1

REFERENCE HYBRID VEHICLE SPECIFICATIONS

Test Weight	1,453 kg
Tire Friction	1%
Aerodynamic Drag-Product Area	0.75 m^2
Acceleration	0-90 km/hr in 15 seconds

Figure 5.2 indicates accident involvement rates by variation from average speed for daylight and night time operation. The probability of an accident increases when a car travels slower or significantly faster than other traffic. Traveling faster than the average traffic speed is controlled by the driver but traveling slower than traffic may be dictated by the capabilities of the vehicle.

Combining the data from Figures 5.1 and 5.2, the rate of accident involvement on various grades is calculated and shown in Fig. 5.3. The reference vehicle is capable of maintaining the 90 km/hr speed limit

[1] D. Solomon, Accidents on Main Rural Highways Related to Speed, Driver, and Vehicle. U.S. Department of Commerce, Bureau of Public Roads, Washington, D.C., July 1964.

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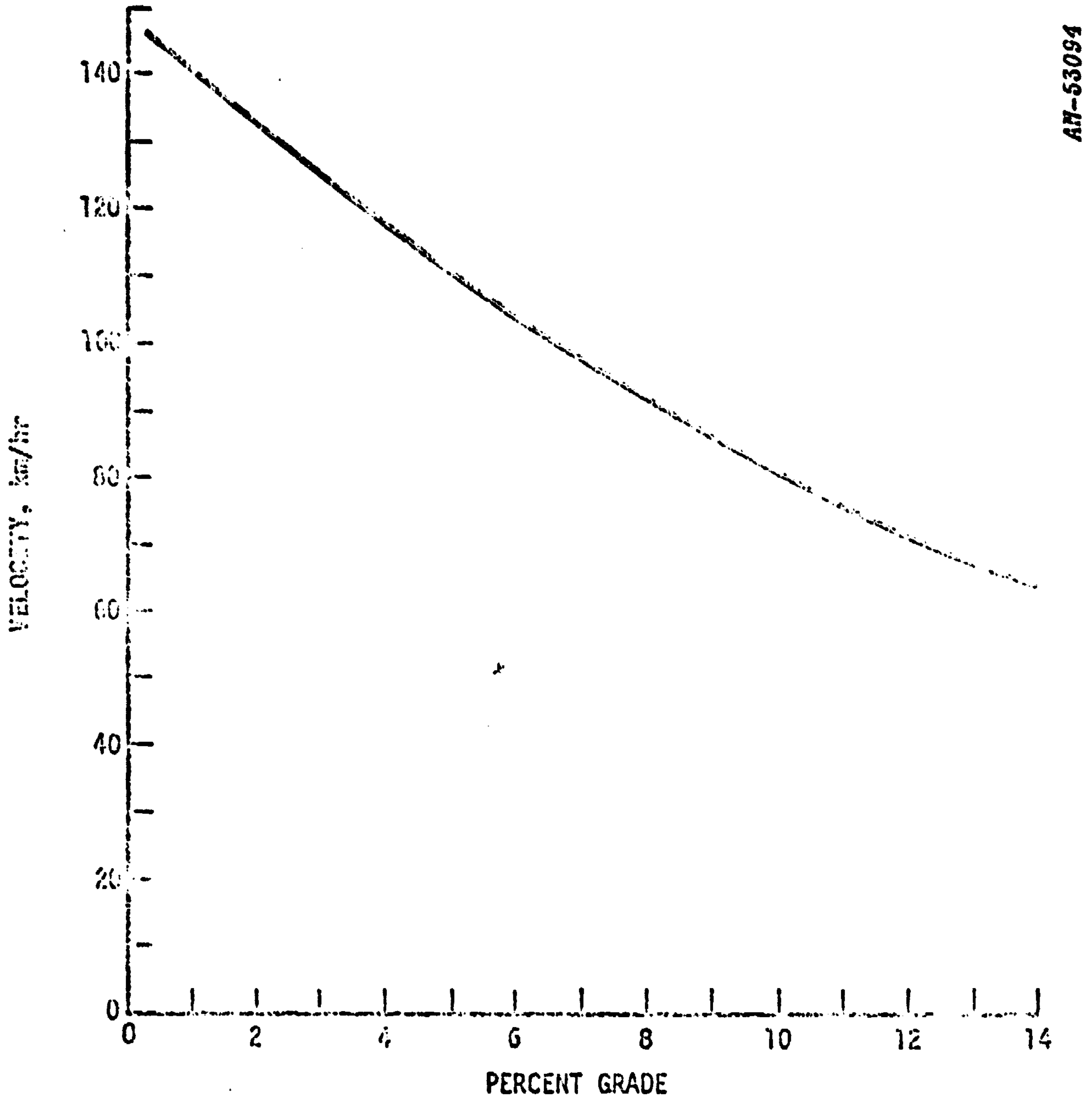
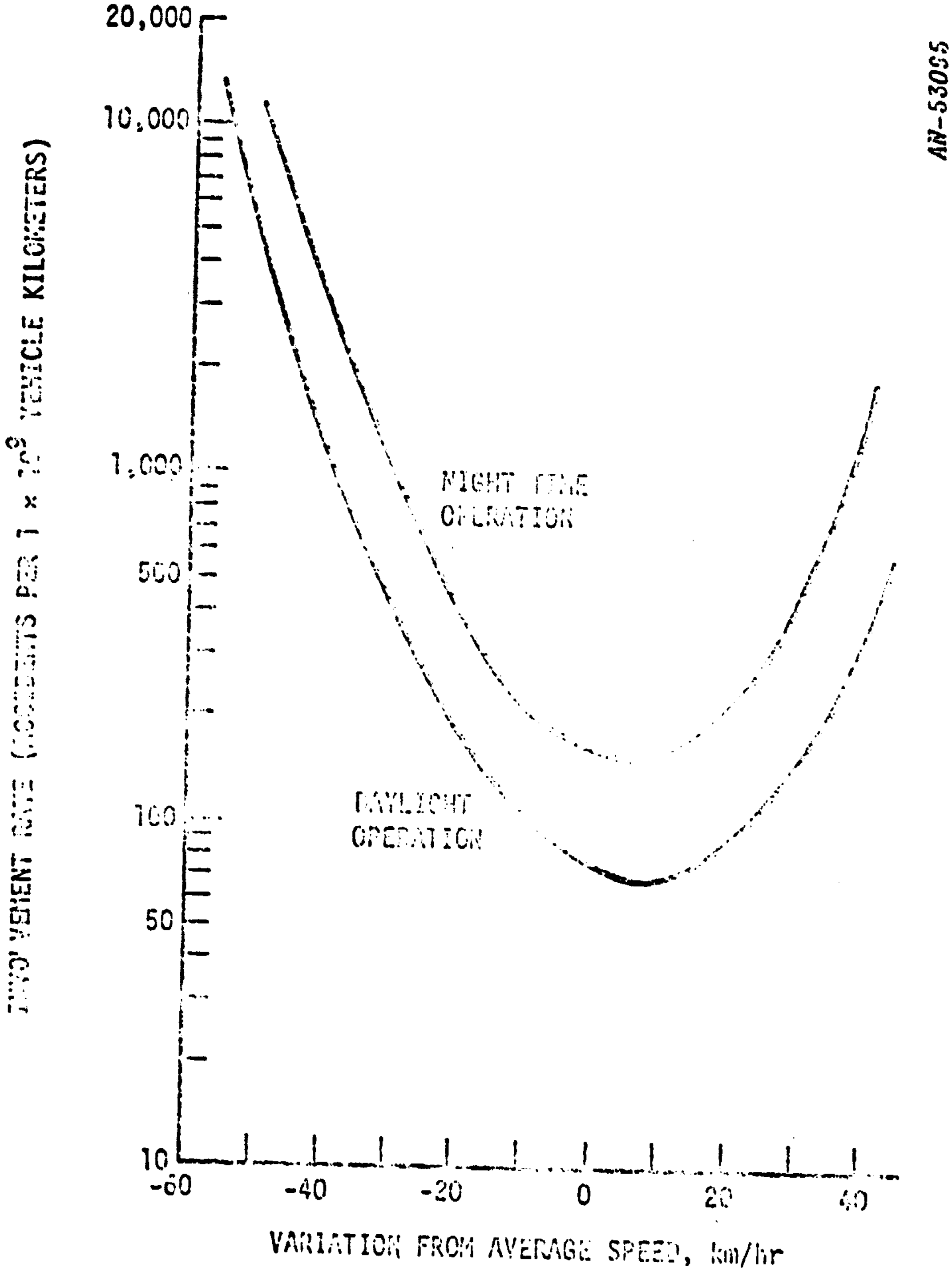


Figure 5.1. Maximum Velocity at Percent Grade for Specified Vehicle



Source: Solomon's Accidents on Main Rural Highways Related to Speed, Driver, and Vehicle

Figure 5.2. Accident Involvement Rate by Variation From Average Speed

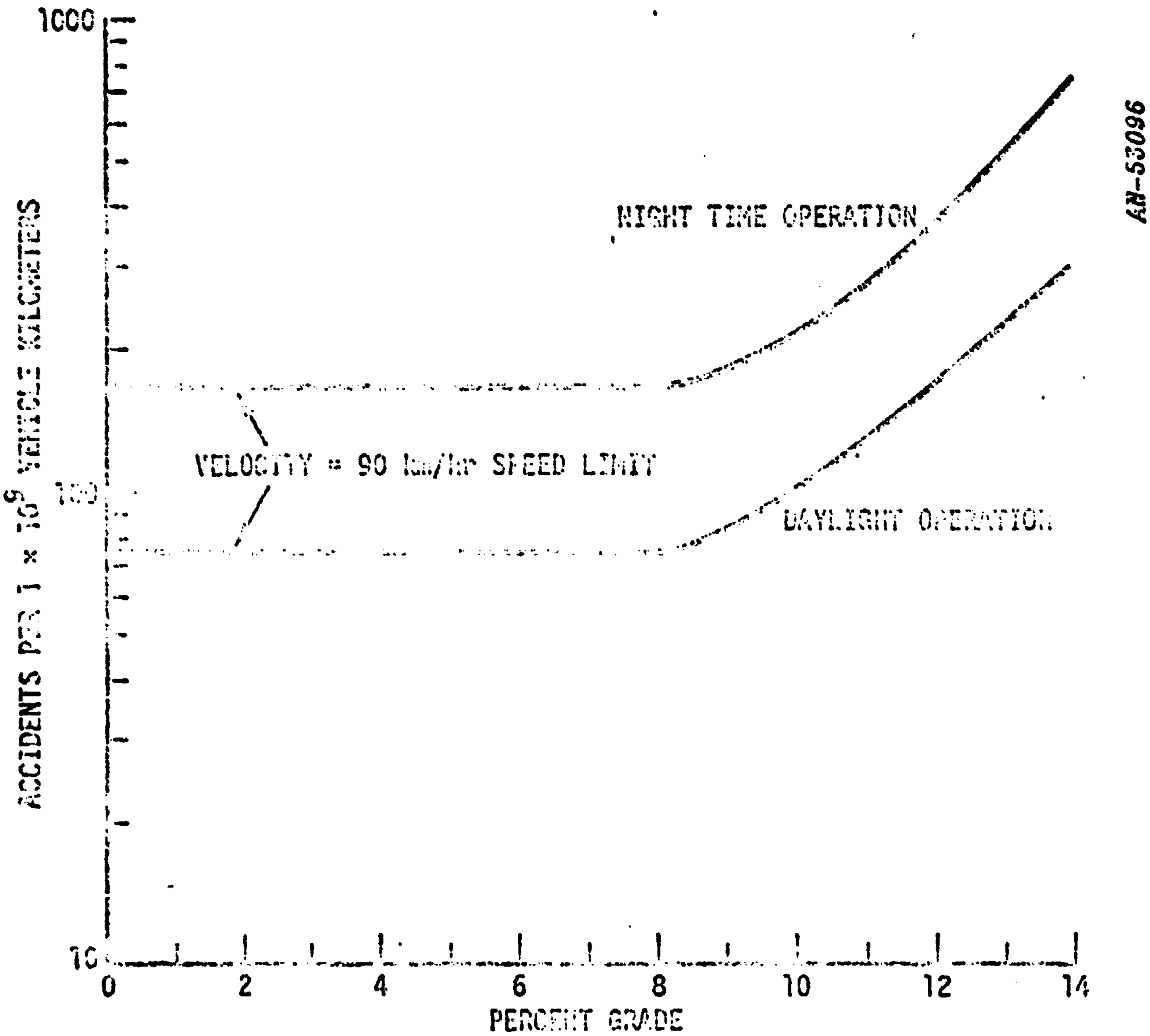


Figure 5.3. Accident Involvement Rate Versus Percent Grade for Reference Hybrid Vehicle

on all grades of 8 percent or less. Since the maximum grade allowable on Federal highways is 6 percent (on which the hybrid can do 112 km/hr) the hybrid vehicle would be able to keep up with freeway traffic. The decrease in the hybrid vehicle's top speed to below 90 km/hr would increase the probable accident rate only on grades over 8 percent, but it is unlikely that such steep roads would allow traffic speeds as fast at 90 km/hr. Therefore, on open roadways the reference hybrid vehicle would not have an accident involvement rate significantly higher than conventional vehicles.

To calculate the expected number of accidents, information is needed on the number of vehicle kilometers traveled on roads of various grades and the average traffic speed maintained.

Road grade data is not easy to obtain, however. Park and Grout[1] did make an estimate of urban and rural grades by terrain type. They estimated for the U.S. as a whole that 63.7 percent of urban highways have grades less than 3 percent, 32 percent are graded between 4 percent and 6 percent, 4 percent have a 6-9 percent grade, and 0.3 percent of the road miles are at grades greater than 9 percent. These estimates were made by comparing Geological Survey elevation maps to Federal Highway Administration data on road miles by region. This methodology does not account for such roadway constructions as switchbacks which would allow roads to be less steeply inclined than the grade of the terrain the road traverses. The data then may contain considerable errors, but no other road grade data have been located.

Even if this tenuous data were used, the expected accident rate could not be calculated since the data does not include the speed at which each grade is traveled.

[1] B. Park, S. Grout, Road Grades - U.S. Distribution of Auto Vehicle Miles (by Region and Urban/Rural), Raytheon Service Company, Cambridge, Massachusetts, May 15, 1974.

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Another safety consideration is the ability of the vehicle to attain a proper merging speed after traveling up an inclined freeway on-ramp. In California the majority of on-ramps onto elevated freeways have a 4 to 6 percent average grade and are 200 to 300 meters long. In the case of the most strenuous on-ramp (200 meters long at a 6 percent grade) the reference hybrid vehicle would be able to attain a 75 km/hr speed by the end of the on-ramp. Since 65 km/hr is considered the minimum safe merge speed,[1] the capabilities of the hybrid vehicle do not pose a safety problem when merging onto an elevated freeway.

[1] N. Rosenberg, et al., Institutional Factors in Transportation Systems and Their Potential Bias Toward Vehicles of Particular Charateristics, Transportation Systems Center, U.S. Department of Transportation, Cambridge, Massachusetts, August 1977.

6 TAXI FLEETS

In 1977, a survey of fleets was undertaken for the Department of Energy to assess the potential for alternate technologies in light-duty highway fleets.[1] Since the questions were aimed at determining the applicability of electric vehicles for fleet use, the data on taxi fleets are helpful in assessing the usefulness of designing a hybrid vehicle to meet the requirements of taxi fleets.

The total cars in U.S. taxi fleets numbered about 336,000 in 1976. The survey included responses from 68 taxi fleets with a total of 2,071 passenger vehicles. The cars were divided into three classes based on weight. "Small" cars were all subcompacts, "medium" cars included 16 percent subcompacts and 84 percent compacts, and the "large" car class was made up of 11 percent compacts and 89 percent mid-sized and large cars.

Sixty percent of the taxis drove over 242 kilometers per day. An implicit daily distance of 251 kilometers per vehicle is derived from the average annual vehicle kilometers (91,770 km). This high daily driving distance would mean that the hybrid taxi would probably use the gasoline-powered propulsion system part of the time. Only a quarter of the vehicles sit idle at a central location for 8 hours, making battery recharging difficult for the majority of taxis.

---

[1] J. Wagner, J. Naughton, and H. Brooks, Light-Duty Highway Fleets: The Potential for Alternate Technologies in Corporate Fleets and In Fleets Operated by State and Local Governments, Interim Briefing for Department of Energy, Economic Analysis Division, National Center of Energy Systems, Brookhaven National Laboratory, New York, April 1978.

TABLE 6.1
TAXI FLEETS

Total Cars in US Taxi Fleets (1976)	336,000
Cars in Taxi Fleets Sampled	2,071
Taxi Fleets Sampled	68
Average Fleet Size	30

	Car Size			
	Small	Medium	Large	Total
Weight Class, kg	Under 1,383	1,383 - 1,588	Over 1,588	
Daily Range, km				
0-80	33%	--	---	0%
81-161	--	16%	2%	5%
162-241	33%	13%	40%	35%
242 and Over	33%	71%	58%	60%
8 Hours Idle at Central Location	15%	17%	27%	25%
Not Requiring Highway Capability	--	49%	38%	40%
8 Hours Idle and No Highway	---	16%	8%	9%
Average Minimum Passenger Space	4.0	4.6	4.6	4.6

Annual Kilometers per Vehicle	91,770
Computed Replacement Age, years	2.8
Computed Replacement Kilometers	231,840

Source: Wagner et al., Light-Duty Highway Fleets

APPENDIX

CALCULATION OF MEAN AND VARIANCE DIRECTLY FROM TABULAR CUMULATIVE DISTRIBUTIONS

Often random variables are described by a tabular presentation of their cumulative probability distribution. Usually the analytical representation of the probability density function for these variables does not exist or is not known. Thus, direct calculation of the mean and variance from Eqs. 1 and 2 is not practical:

$$\mu = \int_{-\infty}^{\infty} x p(x) dx \tag{A.1}$$

$$\sigma^2 = \int_{-\infty}^{\infty} (x - \mu)^2 p(x) dx \tag{A.2}$$

where

μ = mean of x

$p(x)$ = probability density function

σ^2 = variance of x

The following approach allows μ and σ^2 to be calculated directly from the tabular cumulative distribution. Integration of Eq. 1 by parts yields[1]

$$\mu = x P(x) \Big|_{-\infty}^{\infty} - \int_{-\infty}^{\infty} P(x) dx \tag{A.3}$$

where

$$P(x) = \int_{-\infty}^{x} p(u) du$$

If $P(x) = 1 - Q(x)$ is substituted into Eq. A.3 and the lower limit is zero rather than $-\infty$ (as is true for driving distance), we get

[1] F.A. Haight, Mathematical Theories of Traffic Flow, Academic Press, 1963, p. 22.

$$\mu = x[1 - Q(x)]\Big|_0^\infty - \int_0^\infty [1 - Q(x)]dx = \int_0^\infty Q(x)dx \qquad \text{A.4}$$

since $\lim xQ(x) = 0$ as $x \to \infty$.

Using the same approach, it is straightforward to show that

$$\sigma^2 = \int_0^\infty x^2 Q(x)dx - \mu^2 \qquad \text{A.5}$$

Since we are working with tabular data, Eqs. A.4 and A.5 must be rewritten as

$$\mu = \sum_{i=1}^{N} \left[1 - \frac{\left(P_i - P_{i-1}\right)}{2}\right] (x_i - x_{i-1}) \qquad \text{A.6}$$

and

$$\sigma^2 = \sum \left[1 - \frac{\left(P_i - P_{i-1}\right)}{2}\right] x_i^2 (x_i - x_{i-1}) - \mu^2 \qquad \text{A.7}$$

where

P_i = value of cumulative distribution for range of x_i

$P_0 = 0$

$x_0 = 0$

$P_N = 1$

APPENDIX A

MISSION ANALYSIS AND PERFORMANCE SPECIFICATION STUDIES REPORT

SUPPLEMENT

This report contains information prepared by Minicars, Inc. under JPL sub-contract. Its content is not necessarily endorsed by the Jet Propulsion Laboratory, California Institute of Technology, or the National Aeronautics and Space Administration.

MINICARS, INC.
55 Depot Road Goleta, California 93017 (805)964-6271
TELEX 67605, Telecopier (805)964-7669

16 February 1979

Mr. R.C. Kinkade
Mail Station 506/401
California Institute of Technology
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91103

Subject: Submittal of Supplement to Mission Analysis and Performance Specification Studies Report, Task 1, Dated 25 January 1979 - Contract Number 955188

Dear Sir:

In response to your telex of 2 February we are submitting herewith a supplement to our Task 1 Mission Analysis and Performance Specification Studies Report. We regret the omission and appreciate the opportunity to correct the situation. We believe the attached supplement covers the requirements of Paragraph 5(a) and (b) of Data Requirement Description Number 1.

At this time there is no submittal for Paragraph 8. Software developed thus far has been for Task 2 and will be described in that report. Minicars' subcontractor, General Research Corporation, has utilized their Daily Travel Distance (TULDIS) computer program in the performance of their Task 1 effort. However, the software for this program was already in existence, and we believe JPL is in possession of the description of the program.

If you require more details on this program, we would be pleased to respond accordingly.

Sincerely yours,

MINICARS, INC.

S. Romano /mc.

Samuel Romano
Program Manager

SR/cmb

Enclosure

MINICARS, INC.
CONTRACT NO. 955188
TASK 1

16 February 1979
ADDENDUM TO
MISSION ANALYSIS AND PERFORMANCE
SPECIFICATION STUDIES REPORT

MISSION SPECIFICATIONS

A large portion of the information supplied here is already given in our recently submitted Mission Analysis and Performance Specification Studies (hereafter "Mission Analysis") Report, References 1 and 2. We were, however, remiss in not summarizing it in specification form as required by the contract and herewith hasten to correct this omission.

As a result of the NTHV mission analysis, three missions were identified as candidates for further study (Table 1).

Table 1. Mission Descriptions

	Mission	Primary Reason for Selection
A	All-purpose city driving	Maximum potential market penetration
BB	Augmented commuting*	Two-passenger car**
C	Family and civic business	Minimal range requirements

*Includes three 10 km lunchtime or after-work trips per week, in addition to the commuting distance.

**Does not meet JPL constraints.

Specifications and vehicle related characteristics for each of these missions are presented below.

M1 Daily Travel

The distribution of daily travel by mission is given in Figure 3, page 16 of Reference 1. Additional information is presented in Figure 2, page 11, and in the discussion and tables on pages 7-19 of that report.

A summary of the requirements is given below (see also page 15 of Reference 1):

Table 2. Daily Travel by Mission

Mission	Daily Range (km) Average	95th Percentile
A	51	153
BB	43	65*
C	13	38

*Applies to work days which include 10 km of personal trips in addition to driving to and from work. The number differs from Table 5, Mission B of Reference 1, which gives an average over all days.

M2 Payload (in terms of cargo and passengers)

Cargo. Origin-destination survey data do not include the cargo space actually used, only the cargo space available. For 1978 model cars, cargo space availability is described in Table 3.4 of Reference 2. The 95th percentile cargo space for all cars is 0.62 m^3. However, specific vehicles thought to be representative of future full-sized cars show considerably less cargo space - the Audi 5000 with 0.42 m^3 and the Buick Regal with 0.45 m^3. Therefore, the parameter M2 is set at 0.44 m^3 for Missions A and C, which corresponds to the sales-weighted average for all present vehicles. For Mission BB cargo requirements will be minimal.

Passengers. Vehicle occupancy distributions by trip purpose were presented in Table 3.3 of Reference 2. From these data the 95th and 99th percentile occupancy can be established for the various candidate missions. These are shown in Table 3.

Mission BB is assumed to have the same occupancy distribution as Mission B. Note that a five-passenger vehicle will be adequate for all candidate missions at least 95 percent of the time.

M3 Trip Lengths, Trip Frequency, and Trip Purpose

Trip length distributions are shown in Figure 1, page 8 of Reference 1. Trip frequencies are given in Table 5, page 15, and analyzed at length in Appendix A of that report. Trip purposes

Table 3. Vehicle Occupancy by Mission

Mission	95th Percentile Occupancy	98th Percentile Occupancy
A	4.79	5.44
B	2.62	3.72
C	4.41	5.51
All	4.79	5.47

are discussed on pages 3-5 and throughout Reference 1. These are summarized in Table 4.

Table 4. Trip Length, Frequency and Purpose*

Mission	Average Trip Frequency	Trip Length (km)	
		Average	95th Percentile
A	3.74	13.6	41
BB	1.76**	14.6	45
C	1.47	8.65	26

*Purpose is given in Table 1.

**Seven-day average.

M4 Driving Cycles in Terms of FHDC, FUDC, J227a(B)

Each mission is a different set of trips of varying trip lengths and varying average speeds; each trip is a different combination of the three driving cycles. No data were found to distinguish between trip length versus speed relationships for different missions; therefore, the same relationship between trip length and speed was used for all missions. This relationship was indicated in Table B-16 of Reference 1. In that table, Table 5 below, the various combinations of driving cycles are indicated for the various trip lengths. Similar combinations can be, and have been, generated for other trip lengths, and these will be detailed in a subsequent Technical Status Report.

Table 5. Trip Composition for Various Trip Lengths

Trip Length Category (km)	Length (km)	Average Trip Speed (kph)	Trip Description (Kilometers in J227a(B) Cycle, FUDC, & FHDC)
Under 8.0	2.96	17.2	1.316 J227a(B), 0.327 FUDC, 1.316 J227a(B)
8.0-15.3	10.14	32.5	4.81 FUDC, 0.507 FHDC, 4.81 FUDC
15.3-24.9	19.5	43.5	5.25 FUDC, 9.00 FHDC, 5.25 FUDC
24.9-33.0	30.4	54.7	4.35 FUDC, 21.7 FHDC, 4.35 FUDC
33.0-49.1	42.0	64.7	2.86 FUDC, 36.2 FHDC, 2.86 FUDC
49.1-65.2	60.0	79.5	60.0 FHDC
65.2-81.3	78.4	79.5	78.4 FHDC
81.3-160.1	113.3	79.5	113.3 FHDC
160.1+	309	79.5	309 FHDC

M5 Annual Vehicle Miles Traveled per Vehicle

The annual vehicle miles traveled are provided in the JPL Guidelines, Reference 3, Table A-3 for all cars. Annual miles traveled per vehicle by mission are shown in Table 6.

Table 6. Annual Vehicle Miles Traveled per Vehicle

Mission	Annual Travel per Vehicle (miles)
A	11,540
BB	5,890
C	[illegible] 873

M6 Potential Number of Vehicles in Use as a Percentage of Total Vehicle Fleet

The total number of passenger vehicles expected to be in use in 1985 is given in Reference 3 as 113 million. The maximum potential number of vehicles for each mission as a percentage of all vehicles in use can be calculated from the data of Table 5, page 15 cf Reference 1, as follows:

Let n_i = number of trips on mission i on the survey day

$T = \sum_i n_i$ = number of trips driven on the survey day

d_i = number of drivers on mission i on the survey day

$\lambda_i = \frac{n_i}{d_i}$ = average trip frequency, per driver, for mission i

$\mu_i = \frac{n_i}{T}$ = fraction of all trips on mission i

$\frac{T}{D} = \lambda$ = average trip frequency for all missions.

Then
$$d_i = \frac{\mu_i \lambda D}{\lambda_i} \quad .$$

Since each driver must normally be furnished one car, the quantity d_i is also the required number of cars on mission i and d_i/D is the fraction of cars on mission i . This method was used to calculate Table 7.

Table 7. Maximum Potential Passenger Vehicles by Mission as a Fraction of All Vehicles

Mission	μ_i	λ_i	Percent = 100 $\mu_i\lambda/\lambda_i$
A	1	$= \lambda$	100
BB	0.36	2	70
C	0.40	1.47	100

As discussed in Reference 1, this maximum potential must be modified by considering vehicle acceptability, cost and related factors. This work is now in progress.

M7 Reference Conventional ICE Vehicles

The reference conventional ICE vehicle was selected to represent the vehicles that the near term hybrid vehicle could replace. It is a gasoline engine automobile with an inertia weight of 1360 kg and an EPA composite fuel economy of 12.1 km/ℓ. This choice is explained below.

We assume that the NTHV designed in this program will be able to perform all automotive missions well - short trips on electric power alone, and long trips on a combination of both electric and ICE power. On this basis, hybrid vehicles could replace all sizes and types of vehicles in the near term.

However, the size requirement for the proposed NTHV puts a practical limitation on the sizes which can be replaced. The proposed hybrid will be a five-passenger car, which, even with downsizing and weight reductions, would be too large and too heavy to have the efficiency required to replace small or subcompact cars. On the other hand, the NTHV would be too small, as a five-passenger car, to replace the largest vehicles. Therefore, the required size limits its potential to that of a replacement for compact and full sized vehicles. Since each of these sizes of vehicles is estimated in the JPL Guidelines to make up 30 percent of the vehicle market in 1985, a replacement would have the potential of capturing up to 60 percent of the total vehicle market.

The inertia weight and composite fuel economy numbers are averages of the estimated weights and economies of 1985 compact and full-size cars. They give only a very coarse description of the baseline vehicle, and do not contain enough information to allow a direct comparison of the acceleration and economy of this vehicle with the NTHV over specific missions. We therefore used the data developed by Burke (Reference 4) to further define the baseline vehicle. This yields an automobile with the specifications and performance shown in Table 8.

Table 8. Reference Conventional ICE Vehicle Performance Specifications

Vehicle type		Mid-size, five-passenger
Inertia weight		1360 kg
Length		470 cm
Width		185 cm
Height		137 cm
Engine		Gasoline - 63-67 kW
Transmission		4-speed manual or 4-speed OD automatic with lockup torque converter
Acceleration		0-96.6 km/hr in 14 sec
Fuel economy -	composite	12.1 km/ℓ
	city	10.8 km/ℓ
	highway	14.3 km/ℓ
	SAE J227a(B)	7.1 km/ℓ

M8 Estimated Annual Fuel Consumption of Missions Performed Entirely by Reference ICE Vehicles

Table 5 of Reference 1 provides a corase characterization of four missions: A, B, C and D. As explained in the section titled "Daily Travel Distance Distribution," the trip length and the daily travel distributions were found to have the same functional form. This form is illustrated in Figure 1, which applies to both trip length and daily travel distributions for all missions. The functional form allows the construction of a table, such as Table 9, which applies to all missions. The only variation from mission to mission is the variation in λ and L, which are given in Table 5 of Reference 1. When these values are substituted, the average trip length and the average speed are known for each interval of daily travel. Such information permits the construction of driving cycle combinations, as referred to in Item M4 above. With the driving cycle combinations, the fuel consumption per trip can then be obtained for the reference ICE vehicle, and the table can be completed. Use of the tabulated probabilities then permits the calculation of average fuel consumed per trip

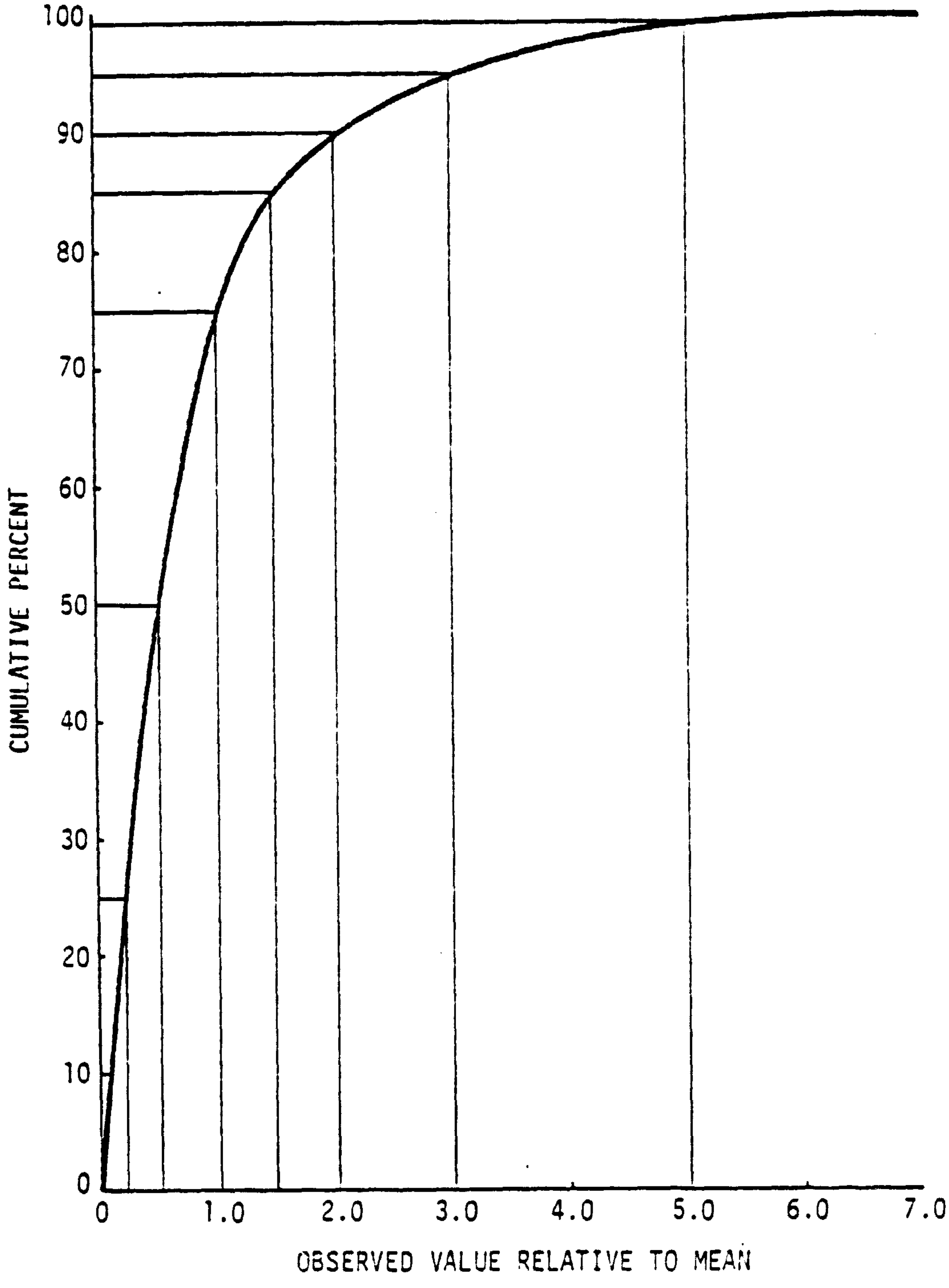

Figure 1. Trip Length and Daily Travel Distribution

Table 9. Travel, Trip Lengths, and Fuel Consumption Distribution

Daily Travel Range	Trip Length Range	Average Daily Travel	Average Trip Length	Fuel Economy	Fuel Per Trip	Cumulative Probability F(x)	Probability p(x)	Average Speed
0-0.22λL	0-0.22L	0.17λL	0.17L			0.25	0.25	
0.22λL-0.50λL	0.22L-0.50λ	0.44λL	0.44L			0.50	0.25	
0.50λL-1.00λL	0.50L-1.00L	0.89λL	0.89L			0.75	0.25	
1.00λL-1.50λL	1.00L-1.50L	1.39λL	1.39L			0.85	0.10	
1.50λL-2.00λL	1.50L-2.00L	1.89λL	1.89L			0.90	0.05	
2.00λL-3.00λL	2.00L-3.00L	2.77λL	2.77L			0.95	0.05	
3.00λL-5.00λL	3.00L-5.00L	4.54λL	4.54L			0.99	0.04	
5.00λL-8.00λL	5.00L-8.00L	7.31λL	7.31L			1.00	0.01	

and per year, as well as the average fuel economy. Such tables are presented for the candidate missions A, B, BB and C (Tables 10 through 13, respectively). The resulting annual fuel consumption is summarized in Table 14.

Table 10. Characteristics of Mission A

L = 13.6, λ = 3.74, λL = 50.9 @ L = 13.6, FE = 10.66 km/ℓ

Daily Travel Range (km)	Average Trip Length (km)	Fuel Economy (km/ℓ)	Petroleum Consumption Per Trip (ℓ)	Probability p(x)	Average Speed (km/hr)
0-11.2	2.31	5.32	0.434	0.25	14.73
11.2-25.5	5.98	7.60	0.787	0.25	25.19
25.5-50.9	12.10	10.41	1.162	0.25	34.91
50.9-76.4	18.90	11.36	1.664	0.10	42.65
76.4-101.8	25.70	11.98	2.145	0.05	49.97
101.8-152.7	37.67	12.79	2.945	0.05	61.06
152.7-254.5	61.74	13.71	4.503	0.04	82.11
254.5-407	99.42	14.05	7.076	0.01	104.61
Average	13.62		1.268		32.85

Average fuel economy = 13.62/1.268 = 10.74 km/ℓ

Average fuel per year = 1.268(3.74)(365) = 1730 ℓ

Average distance per year = 18,596 km

Table 11. Characteristics of Mission B

L = 16.3, λ = 1.33, λL = 21.7 @ L = 16.3, FE = 11.05 km/ℓ

Daily Travel Range (km)	Average Trip Length (km)	Fuel Economy (km/ℓ)	Petroleum Consumption Per Trip (ℓ)	Probability p(x)	Average Speed (km/hr)
0-4.8	2.77	5.52	0.502	0.25	16.40
4.8-10.9	7.17	8.80	0.815	0.25	27.75
10.9-21.7	14.51	10.82	1.341	0.25	37.85
21.7-32.6	22.66	11.72	1.933	0.10	46.91
32.6-43.4	30.81	12.35	2.495	0.05	55.06
43.4-65.1	45.15	13.19	3.423	0.05	67.60
65.1-108.5	74.00	13.90	5.324	0.04	92.83
108.5-174	119.15	14.11	8.444	0.01	104.61
Average	16.33		1.451		36.08

Average fuel economy = 16.33/1.451 = 11.25 km/ℓ

Average fuel per year = 1.451(1.33)(365) = 704 ℓ

Average distance per year = 7934 km

Table 12. Characteristics of Mission BB

Daily Travel Range (km)	Average Trip Length (km)	Fuel Economy (km/ℓ)	Petroleum Consumption Per Trip (ℓ)	Probability p(x)	Average Speed (km/hr)
0-4.8	2.77	5.52	0.502	0.17	16.40
4.8-10.9	7.17	8.80	0.815	0.17	27.75
10.9-21.7	11.55	10.30	1.121	0.49	34.21
21.7-32.6	22.66	11.72	1.933	0.07	46.91
32.6-43.4	30.81	12.35	2.495	0.03	55.06
43.4-65.1	45.15	13.19	3.423	0.03	67.60
65.1-108.5	74.00	13.90	5.324	0.03	92.83
108.5-174	119.15	14.11	8.444	0.01	104.61
Average	14.63 (L)		1.330		35.06

Average fuel economy = 14.63/1.330 = 10.99 km/ℓ

Average fuel per year = 1.330(1.759)(365) = 854 ℓ

Average distance per year = 14.63(1.759)(365) = 9388 km

Average trips per day = 12.310/7 = 1.759 (λ)

Average daily travel = 14.63(1.759) = 25.7 km/day (λL)

Fraction of total trips = $\frac{12.310}{9.310}(36.2) = 47.9\%$

@ L = 14.63, FE = 10.87 km/ℓ

Table 13. Characteristics of Mission C

$L = 8.65$, $\lambda = 1.47$, $\lambda L = 12.7$ @ $L = 8.65$, $FE = 9.51$ km/ℓ

Daily Travel Range (km)	Average Trip Length (km)	Fuel Economy (km/ℓ)	Petroleum Consumption Per Trip (ℓ)	Probability p(x)	Average Speed (km/hr)
0-2.8	1.47	4.85	0.303	0.25	10.93
2.8-6.4	3.81	6.15	0.620	0.25	19.73
6.4-12.7	7.70	9.10	0.846	0.25	28.65
12.7-19.1	12.02	10.40	1.156	0.10	34.83
19.1-25.4	16.35	11.06	1.478	0.05	39.88
25.4-38.1	23.96	11.83	2.025	0.05	48.18
38.1-63.5	39.27	12.87	3.051	0.04	62.46
63.5-102	63.23	13.74	4.602	0.01	83.41
Average	8.67		0.901		26.04

Average fuel economy = 8.67/0.901 = 9.62 km/ℓ

Average fuel per year = 0.901(1.47)(365) = 483 ℓ

Average distance per year = 4635 km

Table 14. Fuel Consumption Summary

Mission	Annual Distance Per Car (km)	Average Fuel Economy (km/ℓ)	Annual Fuel Consumption (ℓ)
A	18,596	10.7	1730
B	7,934	11.3	704
BB	9,388	11.0	854
C	4,635	9.6	483

MISSION RELATED VEHICLE CHARACTERISTICS

V1 Capacity (Passengers and Cargo)

Passengers. Passenger payload is briefly discussed on page 17 of Reference 1. Vehicle passenger capacity required to accommodate most of the occupants on a given mission is given in Table 15.

Table 15. Required Passenger Capacity

Mission	Number of Passengers
A	5
B, BB	2
C	6

Cargo. As discussed in the Mission Specification M2, cargo capacity was set at 0.44 m^3. This was based on two considerations: (1) vehicle downsizing will probably result in smaller trunk volumes than is often the case currently; and (2) people very rarely use more than a small fraction of the available cargo volume.

V2 Range, Speed, Acceleration and Gradeability

Range. Daily travel by mission was given in Table 2. The 95th percentile values for Missions A, BB and C are 153, 65 and 38 km, respectively. When one considers that vehicles currently performing these missions can refuel when necessary, the potential daily travel is limited only by the traveling speed and the endurance of the driver. Therefore, the non-refueled range cannot be correlated to daily travel data. A similar situation holds for the NTHV. Indeed, the range of current vehicles seems to be more a function of attractiveness to the consumer (which has not been evaluated) and space available in the vehicle. In any case, a non-refueled range of 500 km appears to be consistent with current automotive practice.

Speed. Average traveling speeds (average moving speeds obtained on the roadway) are different from the speeds used to characterize varying trip lengths (which include idle time, as do the various driving cycles used in the mission analysis). These speeds were reported in Table 2.7 of Reference 2. The highest freeway speed reported was 106 km/hr for all trip purposes. Therefore, the maximum speed capability required for all missions is considered to be 106 km/hr. This is considerably less than the available maximum speed both for current vehicles and for the hybrid.

Acceleration. As reported in Section 5 of Reference 2, the most strenuous acceleration requirements correspond to going from zero to the minimum safe merging speed of 65 km/hr on a 200 meter on-ramp which has a 6 percent grade. This corresponds to an acceleration capability of 0-65 km/hr in 17 seconds on a level road, and is less stringent than the minimum requirement R5 for acceleration capability.

Gradeability. Figure 5.3 of Reference 2 shows that no increase in the accident rate occurs if a vehicle can maintain the 90 km/hr speed limit at the maximum grade encountered. Since the maximum grade allowable on federal highways is 6 percent, the implication is that a gradeability of 90 km/hr on a 6 percent grade will be adequate for all missions. Slower speeds on steeper grades may be characteristic of missions with shorter trip lengths (such as Mission C), but data for accident rates and grades by trip purpose, and hence by mission, were not obtained.

V3 Cost Constraints (Initial and Operating)

Cost constraints in the real world are imposed by virtue of consumers being increasingly reluctant to purchase vehicles if their costs, both initial and operating, increase. This reluctance is very difficult to assess and, in any case, it would be impossible to obtain a measure of it mission by mission. Therefore, an attempt was made to obtain an estimated life cycle cost for the reference ICE vehicle for each mission. This was done under the following assumptions:

1. Gasoline costs 95.5 cents per gallon, including taxes, in 1985 (1978 cents), in accordance with JPL guideline (B).

2. The discount rate is 2 percent, in accordance with JPL guideline (D)(f).

3. Reference vehicle fuel economy is as reported in Item M8 for the various missions.

4. Costing procedure follows the publication Cost of Owning and Operating an Automobile, 1976 (COA), by L.L. Liston and C.A. Aiken, Federal Highway Administration.

5. Oil consumption and cost of oil bears the same relationship to consumption and cost of gasoline as it does in COA.

6. Items denoted "other operating costs" include maintenance, parking, insurance, and non-petroleum taxes.

7. Other operating costs reflect the average of "standard" and "compact" cars, as categorized in COA, and as discounted from 1976 to 1985.

8. Initial cost corresponds to depreciation in COA, and reflects an estimated growth from current "standard" and "compact" cars to 1985, based on our experience with the Research Safety Vehicle (RSV) and Large Research Safety Vehicle (LRSV), and on consultation with auto industry leaders.

Results of these calculations are shown in Table 16.

Table 16. Cost Constraints

Mission	Fuel Economy (km/ℓ)	Gas & Oil Cost (Incl. Taxes) (¢/km)	Other Operating Costs (¢/km)	Total Operating Cost (¢/km)	Initial Cost (¢/km)	Life Cycle Cost (¢/km)
A	10.7	2.45	6.16	8.61	3.44	12.05
B	11.3	2.34	6.16	8.50	3.44	11.94
BB	11.0	2.39	6.16	8.55	3.44	12.00
C	9.6	2.73	6.16	8.90	3.44	12.34

V4 Ambient Conditions, Availability and Amenities

Ambient Conditions. As a general rule, vehicles used for all missions should be capable of operating in roughly the same range of ambient temperatures as current vehicles. No data regarding different likelihoods of exposure to extreme temperatures as a function of trip purpose were found. Therefore, the required ambient temperature capability is taken to be -20°C to +40°C, in accordance with JPL minimum requirement R8.2.

Availability. Table 4.1 of Reference 2 indicates that 17 percent of all housing units have no car available. This implies that one or more cars are available at 83 percent of all occupied housing units. From that fact one could infer an availability requirement of 83 percent for all missions. However, it would appear that a better definition of availability would relate to whether a vehicle has sufficient fuel (or battery charge), is in an adequate state of repair, etc., such that it is available for a trip in any mission. For electric vehicles the range requirements could very well be a major determinant of availability (at least by this definition), but current and hybrid vehicles can always be refueled enroute. No data were obtained for other determinants of availability, particularly by mission. It would appear that current vehicles have an availability, at least by this definition, of around 99 percent, however, based on common car ownership experience.

Amenities. The popular options which are currently factory-installed on vehicles are listed in Table 17. No data were found to distinguish between one mission and another - particularly in light of the current use of cars for a variety of missions over their lifetimes. Table 17 does provide a guide to the amenities to be found in current vehicles. However, it is obvious that the demand for these options will be especially volatile between now and 1985, with an increasing emphasis expected on electronics and entertainment-oriented features.

Table 17. Popular Options in the 1976 and 1977 Model Years - U.S. Automobiles

Option	Percent of Output 1976	Percent of Output 1977
Air Conditioning	74.91	81.90
Power Brakes	81.75	91.37
Power Steering	90.82	95.80
Power Side Windows	22.67	27.16
Rear Window Defogger	28.94	35.09
Power Seats	16.74	21.20
AM Radio		35.25
AM/FM Radio	82.34	12.88
AM/FM Stereo		29.27
Tape Player	12.61	14.72
CB Radio	---	0.96
Adjustable Steering Column	31.27	39.03
Cruise Control	26.37	36.01
Bucket Seats	24.38	21.53
Vinyl Top	46.68	48.09
Raised Letter/White Sidewall Tires	84.25	90.91
Steel Belted Radials	76.11	79.26
Automatic Transmission	92.94	95.75
3-Speed Manual Transmission	---	0.77
4-Speed Manual Transmission	5.61	3.38
5-Speed Manual Transmission	---	0.10
V-8 Engine	69.83	76.99
6-Cylinder Engine	21.59	18.26
4-Cylinder Engine	8.58	4.75

Source: Automotive News, Market Data Book Issues for 1977 and 1978, Crain Communications, Inc., Detroit, Michigan.

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APPENDIX B

DESIGN TRADE-OFF STUDIES REPORT

SR-4500-05-79 (1)

NEAR TERM HYBRID PASSENGER VEHICLE DEVELOPMENT PROGRAM PHASE I

CONTRACT 955188

DESIGN TRADE-OFF STUDIES REPORT

25 MAY 1979

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27 August 1979

The present document is a revised version of the "Design Trade-Off Studies Report," dated 25 May 1979. The revision consists primarily of an addendum, which is included at the end of the report. Otherwise, only minor changes (mostly typographical) have been made in the text itself.

SECTION 1

INTRODUCTION

The goal of the design trade-off studies is to derive the performance specifications and the preliminary design of a Near Term Hybrid Vehicle (NTHV), a vehicle which will exhibit the greatest potential for petroleum savings in the near term. A methodology, outlined in Figure 1, was constructed and implemented to evaluate the avantages and disadvantages of all hybrid subsystems and components.

For each candidate system package we simulated the hybrid's performance through three driving cycles (SAE J227A(B), FUDC and FHDC). The results of the hybrid vehicle simulation were used to evaluate the petroleum and electricity consumptions and the electric range when the vehicle is taken through the missions specified in Task 1 (Reference 1). Then the results of the mission simulation (the average petroleum and electricity economies) were used in the evaluation of the life cycle cost (LCC) for each NTHV system package.

Task 1 of this program (Reference 2) specified a reference internal combustion engine (ICE) vehicle (Table 1). The LCC of this vehicle, when taken through the missions specified in Task 1, is used to obtain the benefit and the net benefit (the difference between the LCC of the reference ICE vehicle and the LCC of the NTHV) for each NTHV system package.

Using this methodology as a standard, we investigated the following factors:

1. Hybrid power sizing
    a. Battery capacity
    b. Heat engine peak power
    c. Electric motor peak power

2. Battery types
    a. Lead-acid
    b. Nickel-zinc
    c. Nickel-iron

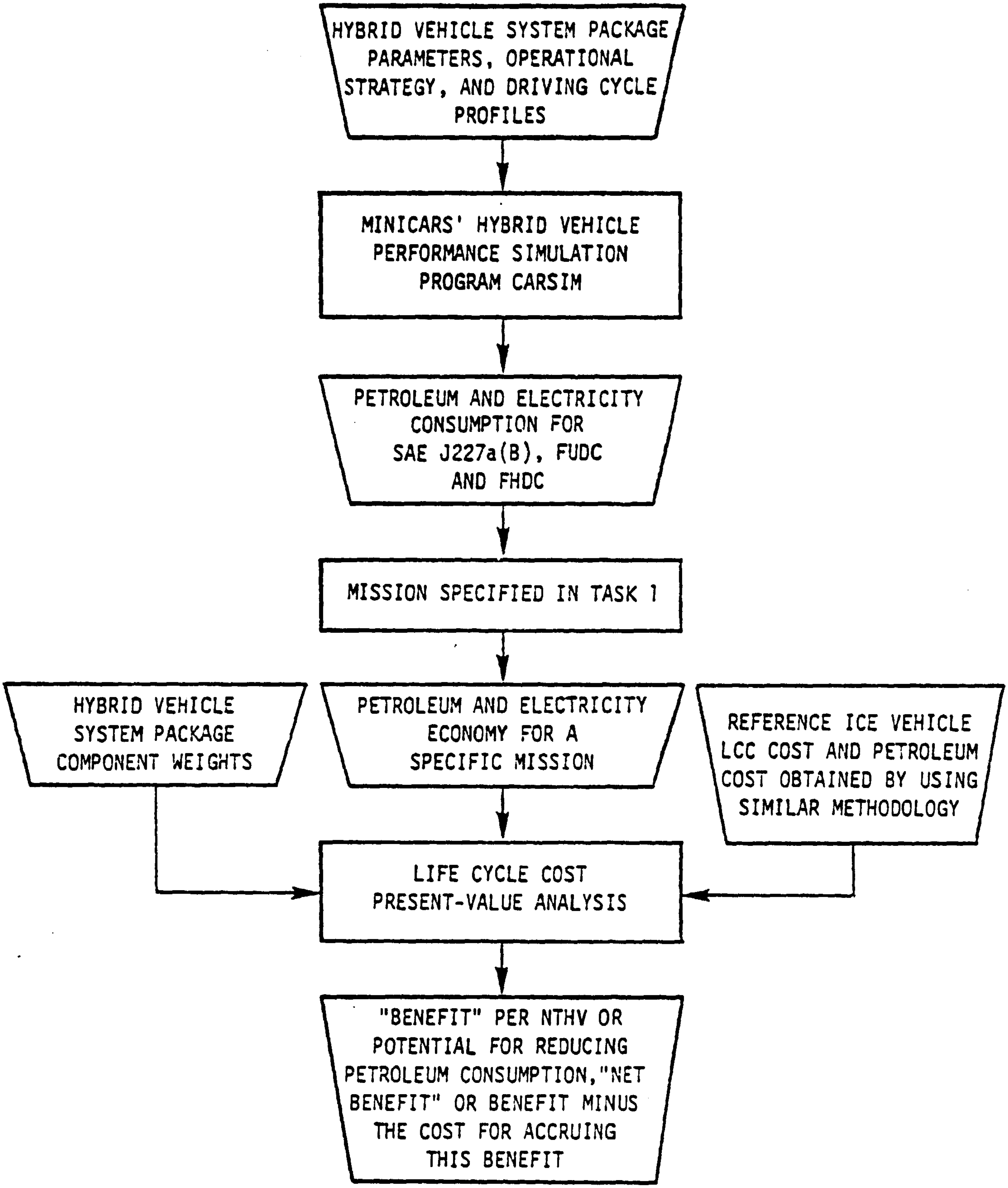


Figure 1. Trade-Off Studies Methodology for Each NTHV System Package

Table 1. Reference Conventional ICE Vehicle Performance Specifications

Vehicle Type		Mid-size, five-passenger
Inertia weight		1360 kg
Length		470 cm
Width		185 cm
Height		137 cm
Engine		Gasoline - 63-67 kW
Transmission		4-speed manual or 4-speed OD automatic with lockup torque converter
Acceleration		0-96.6 km/hr in 14 sec
Fuel economy -	composite	12.1 km/ℓ
	city	10.8 km/ℓ
	highway	14.3 km/ℓ
	SAE J227a(B)	7.1 km/ℓ

3. Battery parameters
   a. Cycle life
   b. Initial state of discharge
   c. Final depth of discharge

4. Heat engine types
   a. Turbocharged diesel
   b. Naturally aspirated diesel
   c. Reciprocating spark ignition
   d. Stratified charge reciprocating spark ignition

5. Electric motor types
   a. DC shunt
   b. DC series
   c. DC compound

6. Controller

7. Charger

8. Transmission types
   a. Five-speed manual
   b. Three-speed automatic

9. Transmission parameters
   a. Transmission ratios
   b. Final drive

10. Regenerative braking

11. Hybrid accessories
    a. Air conditioning
    b. Other accessories
    c. Accessory operational strategy

12. Hybrid vehicle cold start

13. Heating and defrosting

14. Vehicle operational strategies

15. Microcomputer

16. Vehicle inertia weight

17. Aerodynamic drag resistance

18. Rolling resistance

19. Electric range

20. Acceleration

21. Gradeability

22. Hybrid vehicle marketability

23. Life cycle costs

The parameters which govern the maximization of petroleum savings are numerous. We therefore analyzed this parametric set in subsets, or suboptimizations. The operational strategy was approached as a separate subset of the trade-off studies. The connection between the component trade-offs and the operational strategies was then made in an iterative manner.

Initially, we investigated all of the NTHV system packages using the most promising operational strategy. The object of this operational strategy is to deplete the batteries to their maximum allowable state of discharge at the end of the day. In this strategy the electric motor is used as the primary drive component until the batteries are depleted to their maximum allowable discharge. Then the heat engine becomes the primary drive component.

Several other operational strategies were tested and their impacts on petroleum savings observed. But we found that these impacts were not sufficient to warrant the new set of design component trade-offs which would be required by a new suboptimum operational strategy.

Based on the preliminary trade-off studies (Reference 5), the performance analyses (Reference 4) and the review of the designs reported in the literature, we have specified a baseline NTHV whose specifications and performance parameters are given in Tables 2 and 3, respectively. Most of the hybrid parameters are investigated using the baseline NTHV.

The NTHV system packages reported first do not include accessories, and work under the assumption of a warm start. The effects of a cold start and the addition of accessories are reported in their own sections. We performed all of the trade-off studies by taking the NTHV system packages through Mission A, which covers 98.8 percent of all trips (Reference 1). All costs given in this report are reported in 1978 dollars.

Table 2. NTHV Preliminary Specifications

Vehicle	Modified 1980 GM "X" Body
Wheelbase	265 cm
Curb weight	1660 kg
Engine	Turbocharged Volkswagen Rabbit Diesel
Displacement	1471 cc
Bore	76.5 mm
Stroke	80.0 mm
Compression ratio	23:1
Masimum power	48.5 kW @ 5000 rpm
Maximum torque	119 Nm @ 3000 rpm
Motor	D.C. Shunt Motor
Power	24 kW
Voltage	72 V
Maximum rpm	5000 rpm
Base speed	1650 rpm
Controller	Transistorized field chopper
Battery	Improved State of the Art Lead-Acid
Voltage	72 volts (twelve 6 volt batteries)
Capacity	12.6 kW-hr (3 hour rate)
Weight	336 kg
Transaxle	Volkswagen Rabbit Modofied
Number of gears	5
Ratios 1	3.45:1
2	1.94:1
3	1.29:1
4	0.97:1
5	0.75:1
Final drive ratio	3.90:1
Tires	P205/75 R14

Table 3. Baseline NTHV Vehicle Performance Specifications

P1	Minimum Non-Refueled Range		
	P1.1 FHDC		702 km
	P1.2 FUDC		511 km
	P.13 J227a(B)		448 km
P2	Cruise Speed		88 km/hr
P3	Maximum Speed		
	P3.1 Maximum speed		180 km/hr
	P3.2 Length of time maximum speed can be maintained on level road		1 min
P4	Accelerations		
	P4.1 0-50 km/hr (0-30 mph)		5 sec
	P4.2 0-90 km/hr (0-56 mph)		12 sec
	P4.3 40-90 km/hr (25-56 mph)		9 sec
P5	Gradeability (Heat Engine Only)*		

	Grade	Speed
P5.1	3%	120 km/hr
P5.2	5%	100 km/hr
P5.3	8%	80 km/hr
P5.4	15%	44 km/hr
P5.5 Maximum Grade	26%	

P5	Payload Capabity	520 kg
P7	Cargo Capacity	0.5 m^3
P8	Consumer Costs	
	P8.1 Consumer purchase price (1978 $)	$8519
	P8.2 Consumer life cycle cost (1978 $)	$0.13/km

*In diesel drive distance is limited by fuel tank capacity

Table 3 (Cont'd)

P9	Emissions - Federal Test Procedure	
	P9.1 Hydrocarbons (HC)	0.19 gm/km
	P9.2 Carbon monoxide (CO)	0.56 gm/km
	P9.3 Nitrogen oxides (NO_x)	0.98 gm/km
P10	Ambient Temperature Capability	
	Temerature range over which minimum performance can be met	-20°C to +40°C
P11	Rechargeability	
	Maximum time to recharge from 80% depth-of-discharge	5 to 7 hrs
P12	Required Maintenance	
	Routine maintenance required per month	1 hr
P13	Unservices Storeability	
	Unserviced storage over ambient temperature range of -30°C to +50°C (-22°F to +122°F)	
	P13.1 Duration	120 days
	P13.2 Warm-up time required	1 to 2 min
P14	Reliability	
	P14.1 Mean usage between failures - powertrain	40,000 km
	P14.2 Mean usage between failures - brakes	40,000 km
	P14.3 Mean usage between failures - vehicle	40,000 km
P15	Maintainability	
	P15.1 Time to repair - mean	5.0 hrs
	P15.2 Time to repair - variance	2.0 hrs
P16	Availability	
	Minimum expected utilization rate (i.e., 100 X time in service ÷ (time in service + time under repair)	97%
P17	Additional Accessories and Amenities	List
	Air conditioner	
	Cooling fan	
	Alternator	
	Air pump	

SECTION 2

TRADE-OFF METHODOLOGY

2.1 HYBRID VEHICLE PERFORMANCE SIMULATION

We modified Minicars' vehicle performance simulation program, CARSIM, to include the electrical components of a hybrid vehicle, the scaling procedure of a heat engine, and a number of control strategies to be selected by prescribing the necessary program inputs. Because the methodology of CARSIM is reported in References 5 and 6, only the input parameters and output information of the modified program will be discussed here.

The input variables consist of data for the overall vehicle, transmission, heat engine, heat engine fuel consumption, heat engine maximum torque, electric motor, batteries, accessories and control strategy, as well as the transmission shift curves for the heat engine alone, for the electric motor alone, and for the hybrid modes.

The velocity-time profiles for the different driving cycles are stored in a separate file which is available for use by CARSIM. A particular driving cycle can be repeated a number of times to calculate the available range or to establish the effect of an initial state of battery discharge on petroleum and electricity consumption. The flow diagram of CARSIM and typical input data set for an NTHV system package are given in Appendix A.

Once a hybrid system package is inputted to CARSIM, the program simulates the vehicle's performance for a prescribed control strategy through a desired driving cycle with a warm start. The output information can be recorded in detail for each second of the driving cycle or in summary for the whole driving cycle. A typical output set is also given in Appendix A.

2.2 MISSION SIMULATION

After the hybrid vehicle performance under a given operational strategy was simulated for each of the three driving cycles, we used combinations of these cycles to represent the distribution of trip lengths for a specific mission. These combinations were then used in the evaluation of the petroleum and electric economies. The representative driving cycle for a given trip length was constructed from segments of these driving cycles (References 1, 3 and 5).

The petroleum and electricity consumptions in a cycle were assumed to be linear functions of the distance traveled (as verified by samples given in Figures 2 and 3). So the petroleum and electricity consumptions per cycle obtained from CARSIM could be linearly segmented and used in constructing representative driving cycles.

We also found the effect of the initial state of battery discharge on the driving cycle consumptions during a day. If the initial state of discharge (initial to each trip, as well as at the beginning of the day) has considerable effect on the petroleum and electricity consumptions per driving cycle, then the hybrid vehicle has to be taken through a mission by taking into account the sequence of trips during a day. We assumed that the battery state of discharge is zero in the morning. The effects of the initial state of discharge for the rest of the trips during the day were obtained by simulating the baseline NTHV on CARSIM for various initial states of battery discharge (0.0, 0.1, 0.2, 0.3, 0.4 and 0.5). The results are shown in Figures 4, 5 and 6. Then, by using the Mission A trip length distribution, we obtained the initial state of battery discharge probabilities during a day. The results are given in Table 4.

Table 4 shows that in 48.75 percent of the trips during a day the initial state of battery discharge is between 0.0 and 0.1. Figures 4, 5, 6 and Table 4 were used to determine the weighted petroleum and electricity consumptions. The correction factors to obtain the weighted consumption averages, given zero initial battery discharge, are listed in Table 5.

Typical petroleum and electricity consumptions per cycle, averaged over the initial states of battery discharge, are presented in Table 6. Given the petroleum and electricity consumptions averaged over the initial states of discharge, and an average number of trips per day, the computer program MISSIM was used to calculate the consumptions for a specified mission. The listing of this program is given in Appendix B.

The input parameters to the program are

a. The average trip length of a trip length bin and its probability of occurrence

b. SAE J227a(B), FUDC and FHDC average velocities and lengths

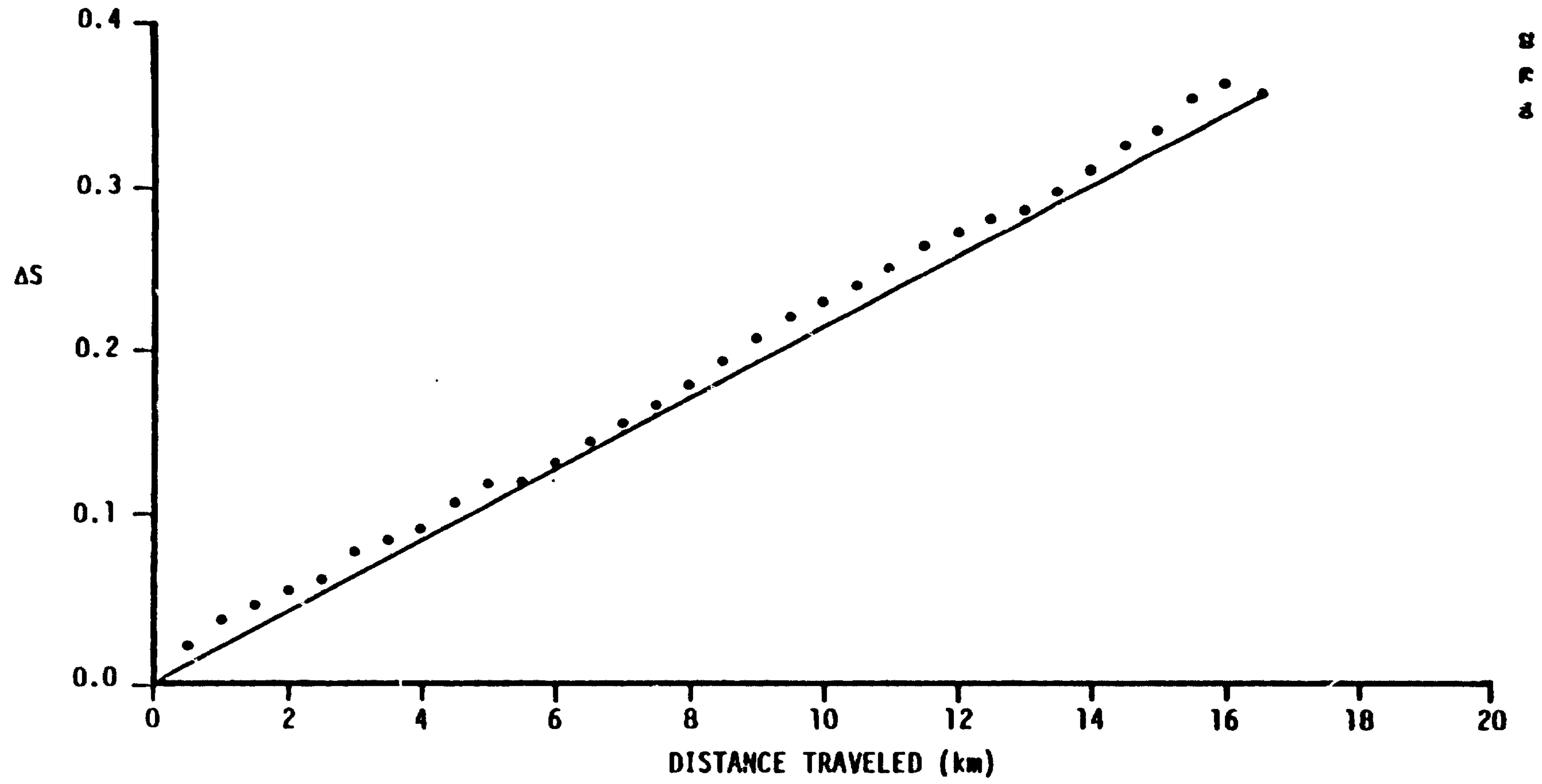


Figure 2. Electricity Consumption as a Function of Travel Distance for FHDC with Electric Motor as the Primary Drive Component and the Heat Engine as the Secondary Drive Component

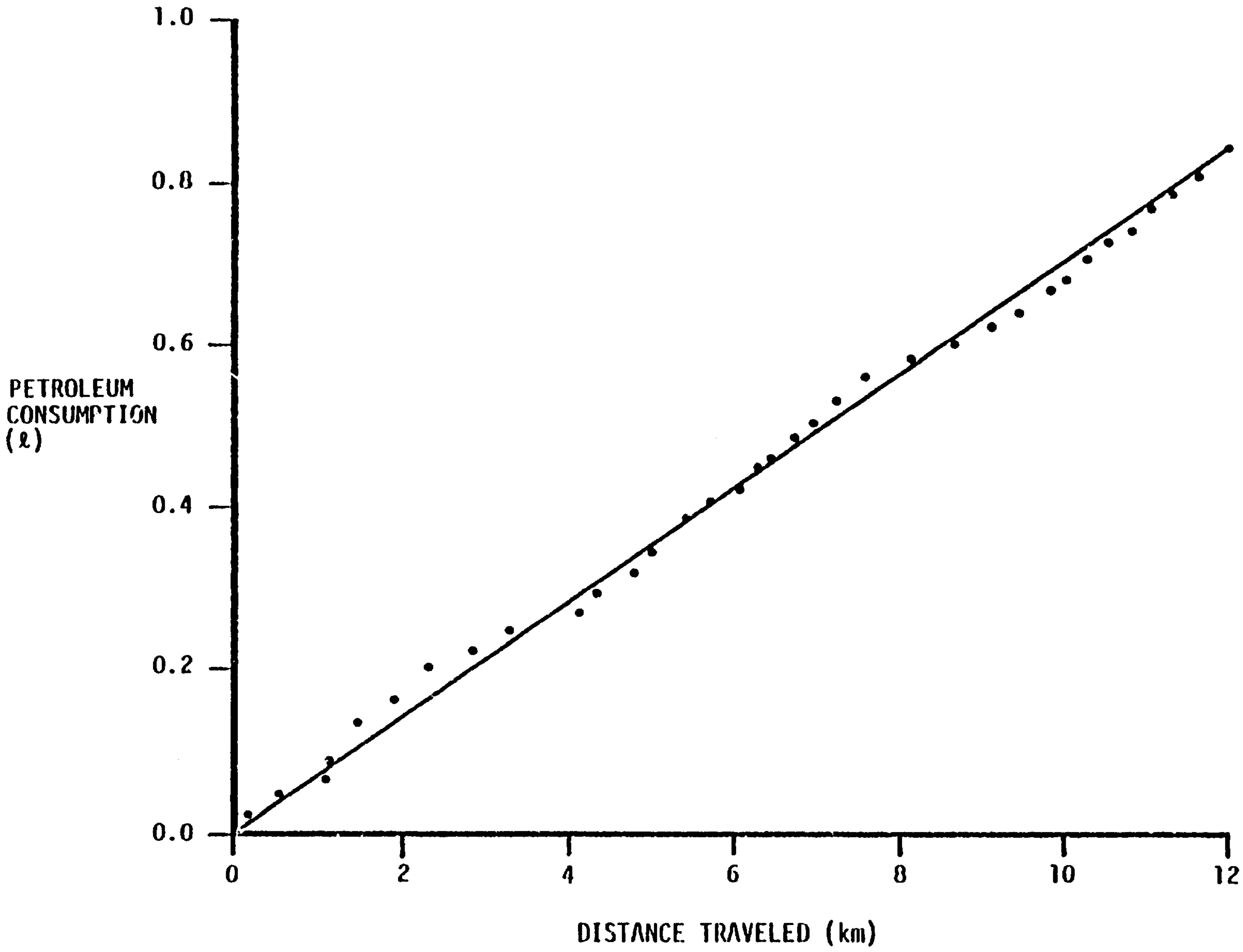


Figure 3. Petroleum Consumption as a Function of Travel Distance for FUDC with Heat Engine as a Primary Drive Component and the Electric Motor as the Secondary Drive Component

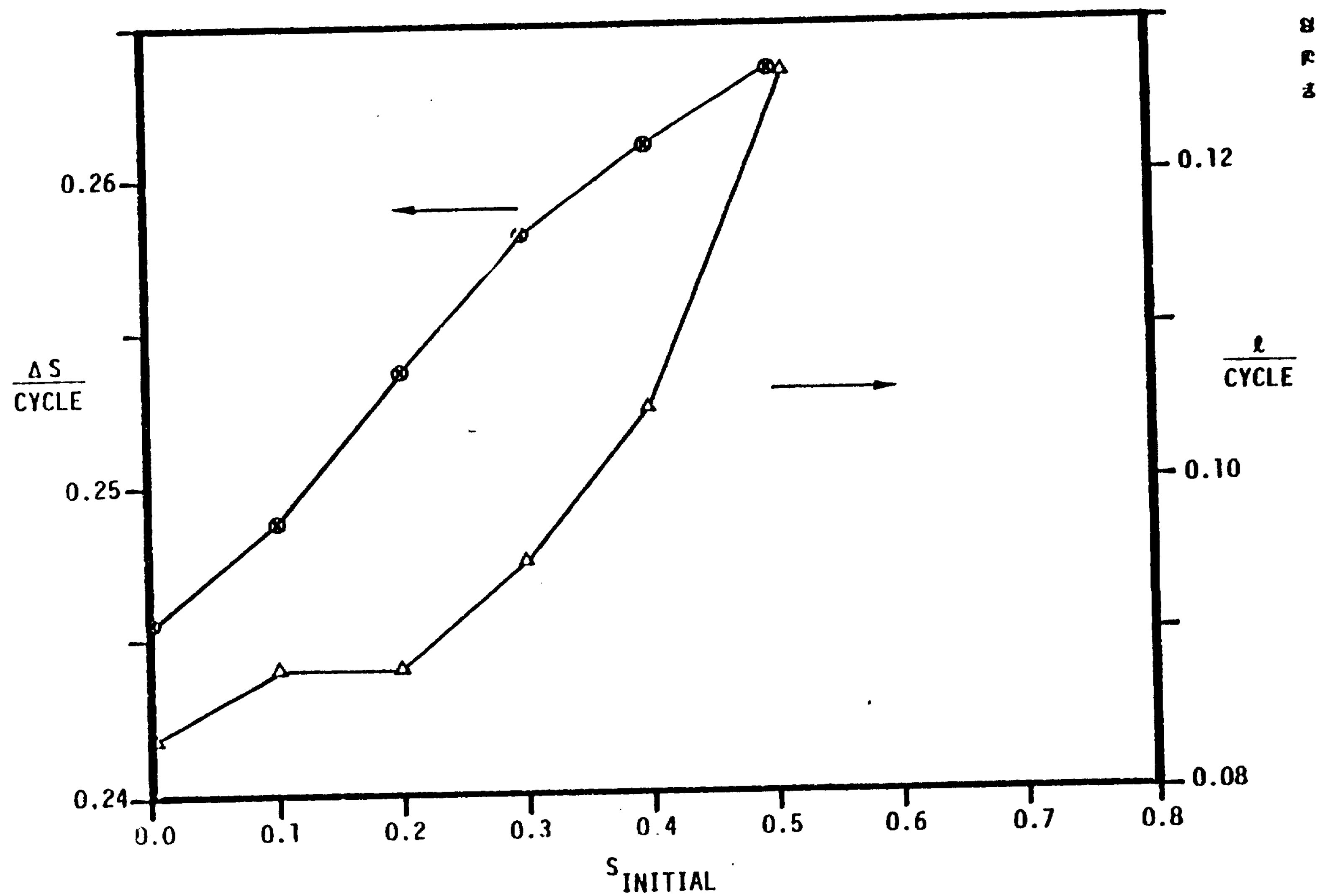


Figure 4. Petroleum and Electricity Consumptions for FUDC with Different Initial States of Battery Discharge; Electric Motor is the Primary Drive Component, and Heat Engine is the Secondary Drive Component

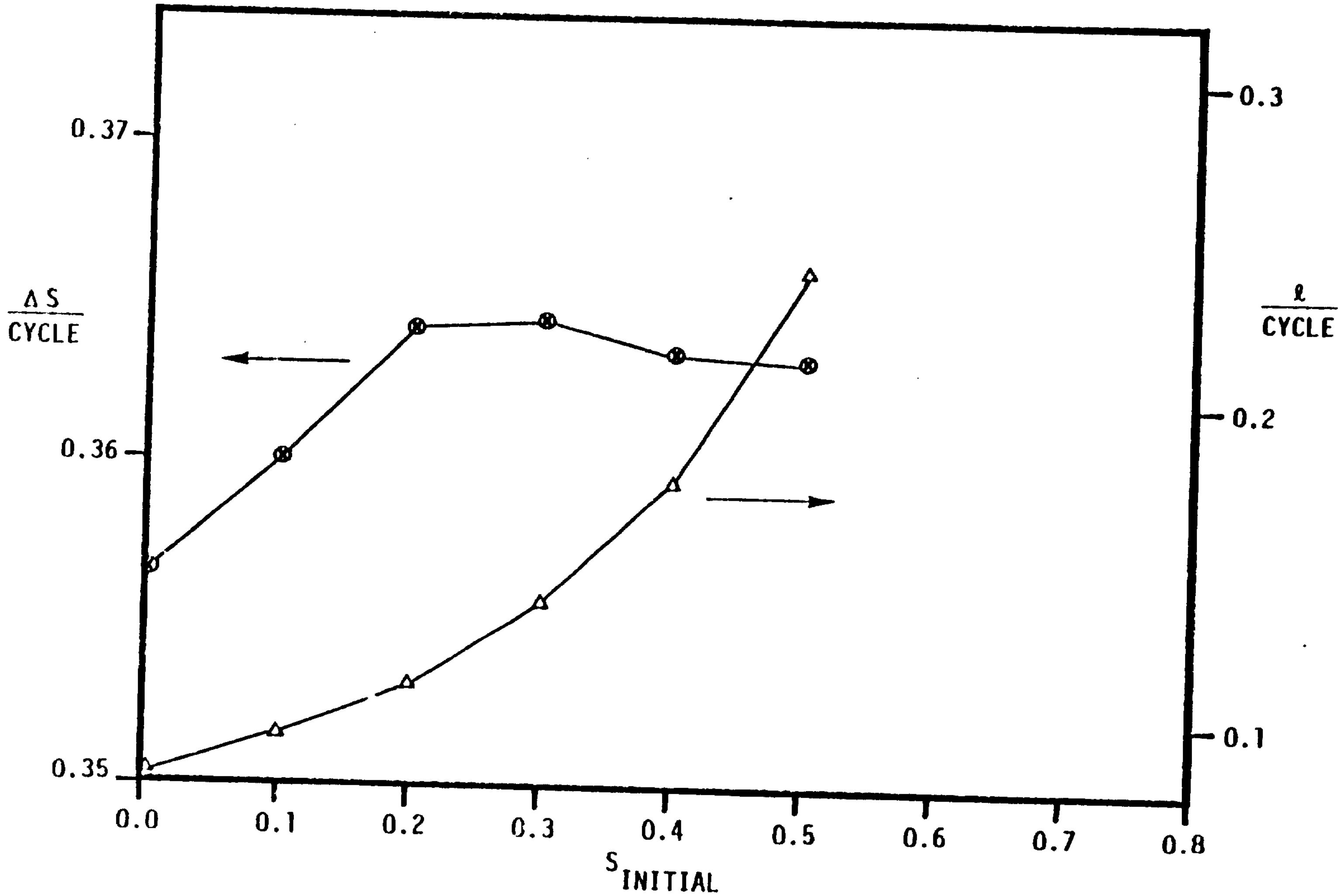


Figure 5. Petroleum and Electricity Consumption for FHDC with Different Initial States of Battery Discharge; Electric Motor is the Primary Drive Component, and Heat Engine is the Secondary Drive Component

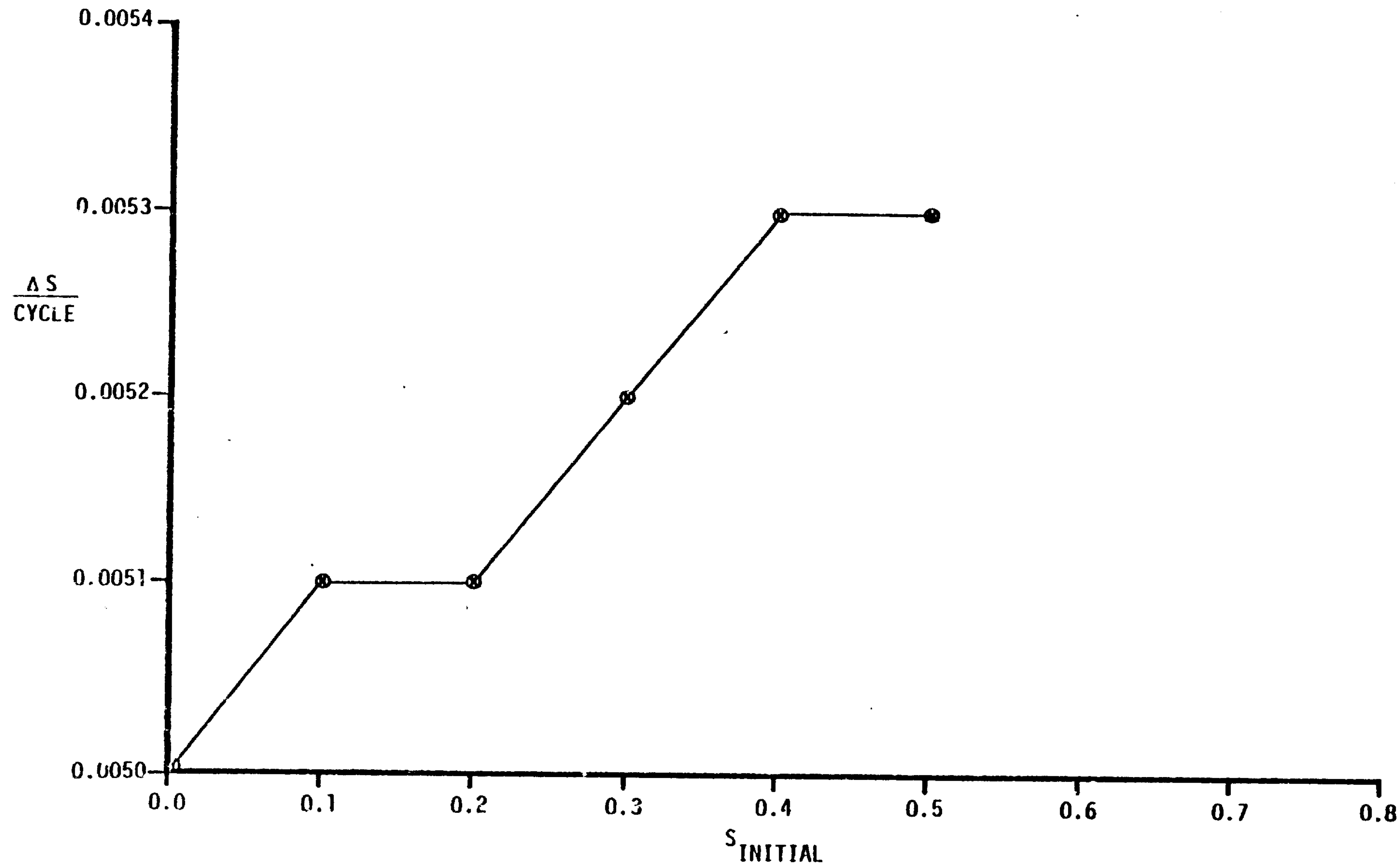


Figure 6. Electricity Consumption for SAE J227a(B) with Different Initial States of Battery Discharge; Electric Motor is the Primary Drive Component, and Heat Engine is the Secondary Drive Component

Table 4. Initial State of Battery Discharge Probabilities During a Day for Mission A

Initial State of Discharge	Probability of Occurrence
0.0-0.1	0.4875
0.1-0.2	0.1455
0.2-0.3	0.1455
0.3-0.4	0.1125
0.4-0.5	0.0840
0.5-0.6	0.0250

Table 5. Correction Factors for Weighted Consumption Averages*

Driving Cycle	Electrical Consumption Correction Factors	Petroleum Consumption Correction Factors
SAE J227a(B)	1.0200	1.0000
FUDC	1.0191	1.0642
FHDC	1.0090	1.2816

*Zero initial battery discharge; electric motor as primary and heat engine as secondary drive component.

Table 6. Initial Battery Discharge, Averaged Petroleum and Electricity Consumptions

Driving Cycle	Electricity Consumption (ΔS/cycle)	Petroleum Consumption (ℓ/cycle)	Cycle Length (km)
SAE J227a(B)	0.0051	0.0000	0.326
FUDC	0.2504	0.0889	12.050
FHDC	0.3598	0.1065	16.400

c. SAE J227a(B), FUDC and FHDC petroleum and electricity consumptions per cycle for zero initial battery discharge

d. Average number of trips per day, final allowable battery discharge during the day, battery capacity and battery charger efficiency.

Appendix B lists a typical input data set for the baseline NTHV in Mission A.

The output of the program first shows the representative driving cycle combinations for each trip length bin. The average trip length, average daily travel, average speed, electric motor primary drive distance, battery consumption per day, electrical consumption per day, electric economy, petroleum consumption per day, petroleum economy, and probability of occurrence are reported for each trip length bin. Then the weighted averages, the electricity consumption per year, and the petroleum consumption per year are outputted, followed by the daily electrical and petroleum consumptions in each trip length bin for the two operational strategies. Finally, the weighted averages and the petroleum and electricity economies are given for the two strategies. Appendix B also includes an output listing.

2.3 SYSTEMS TRADE-OFF IN TERMS OF NET BENEFIT

The trade-off studies started with the vehicle performance simulation, took the vehicle through a specified mission, and ended with an economic analysis of the NTHV system package. The system package economic analysis was performed by estimating life cycle costs using a present-value method. The details of this analysis are given in Appendix C. The unit manufacturing costs of the components were obtained, as planned, from Rath and Strong and from References 7 through 10.

For the reference ICE vehicle, the life cycle costs were obtained first, using the same methodology as for the NTHV. The reference conventional ICE vehicle for 1985 is described in References 2 and 11 as a 1360 kg (inertia weight) vehicle with an overall length of 470 cm. The cost and the weight data of this vehicle's components were synthesized from References 7 and 8, while the petroleum price forecasts and the values for the vehicle kilometers traveled versus the age of the vehicle were obtained from Reference 12. The present value of the life cycle costs was calculated to be

0.10625 $/km for the reference vehicle when used in Mission A. A detailed output of the LCC analysis is shown in Appendix C. The present value of the petroleum cost for the reference vehicle was found to be $4378.51, and the present value of the total life cycle cost was $19,927.82. These values were compared to the economic results for the NTHV system packages in Mission A.

The LCC estimates for the baseline NTHV are given in Appendix C. The present value of the life cycle costs was calculated to be 0.13110 $/km. A summary of the baseline NTHV life cycle cost estimates is presented in Table 7. There are substantial differences between the total acquisition, total energy, and total battery replacement costs of an NTHV and a reference conventional ICE vehicle. (The battery life cycles and the battery costs for this economic analysis were obtained from Reference 9.) For the case presented in Table 7, the benefit per NTHV is $3072, and the net benefit per NTHV is $-4660.

The negative net benefit led us to a search of breakeven petroleum prices, at which the life cycle cost of ownership of the NTHV is equal to that of the reference vehicle. For the case presented in Table 7, the breakeven petroleum price is 0.52 $/liter (1.97 $/gallon). The benefit for the baseline NTHV system package is 70.15 percent of the maximum possible. If 100 percent benefit is desired, we would have to move to an all-electric vehicle, whose breakeven petroleum price is 2.34 $/liter (8.84 $/gallon) for a 122 km range vehicle.[13] This result places the hybrid in a strong position to replace the reference conventional vehicle in the near term.

Table 7. Present-Value Life Cycle Cost Comparisons Between the NTHV and the Reference ICE Vehicle (1978 Dollars)

	Costs	Baseline NTHV	Percent of Total	Reference ICE Vehicle	Percent of Total
1.	Total acquisition cost	10,753	43.74	8,372	43.[illegible]
2.	Total energy cost	2,678	10.39	4,379	21.97
3.	Total maintenance and repair cost	2,154	8.76	2,020	10.13
4.	Total battery replacement cost	3,621	14.73	-	-
5.	Total other operating cost	5,312	21.60	5,158	25.88
6.	R&D cost	68	0.28	-	-
	Total LCC	24,586	100.00	19,929	100.00

SECTION 3

VEHICLE CONCEPT

3.1 BASE VEHICLE

In the Technical Proposal we listed three possible base vehicle for the NTHV: an Audi 5000 modified to accommodate a hybrid power train, a General Motors "A" body vehicle (Chevrolet Malibu, Pontiac La Mans, Oldsmobile Cutlass, or Buick Century) converted to a front wheel drive hybrid, or a completely new vehicle, designed as a hybrid. To these possibilities the Design Trade-off Studies added a fourth: to modify a 1980 General Motors "X" body vehicle into a hybrid. Of these four alternatives we feel that the fourth is the best. It will yield the best hybrid vehicle.

The 1980 General Motors X body is a front wheel drive vehicle which has just been introduced. It is being sold, in slightly different versions, as the Chevrolet Citation (replacing the Nova), Pontiac Phoenix, Oldsmobile Omega, and Buick Skylark. All of these vehicles have transverse-engine front wheel drive and a choice of a 2.5 liter four cylinder or a 2.8 liter 60 degree V-6 engine.

In General Motors' extensive downsizing and weight reduction program the 1980 X body represents the state of the art in packaging and weight reduction for a five passenger vehicle and is a very good base upon which to build a near term hybrid. Since it is a front wheel drive, the conversion will be simplified.

3.2 POWER TRAIN CONFIGURATION

We have made the initial decision that the Minicars NTHV will be a parallel rather than a series hybrid. That is, both the heat engine and the electric motor will propel the vehicle directly, either separately or together—rather than the electric motor providing all of the propulsion and the heat engine driving only a generator. The parallel hybrid system is more efficient than the series hybrid because it eliminates the double efficiency loss which occurs when the heat engine is the primary source of power.

SECTION 4

BATTERY CAPACITY, ELECTRIC MOTOR AND HEAT ENGINE POWER SIZING

Initially, the trade-off studies concentrated on three major governing parameters of an NTHV system: battery capacity, electric motor peak power, and heat engine peak power. We followed the tradeoff methodology described above. During these studies the peak power to weight ratio was assumed to be 0.04 kW/kg.

The GM X-body vehicle weights 1090 kg. If the total weight of the NTHV is higher than this, then the X-body will have to be reinforced. To account for the reinforcements, we take the difference of the two weights and add 30 percent[14] of that number to the total weight of the NTHV.

In this simulation we used ISOA lead-acid batteries with a battery life of 800 cycles (Reference 9). The lead-acid battery capacities were taken to be 8.4, 10.5, 12.6, 14.7, 15.75, and 16.8 kW-hr. The electric DC shunt motor peak powers were assumed to be 14, 19, 24, 29, and 34 kW. The corresponding heat engine peak powers for a turbocharged diesel engine vary between 31.2 and 64.6 kW, depending on the peak power of the electric motor. And the NTHV inertia weights vary between 1630 and 1964 kg, depending on the system package used.

Each system package was put through CARSIM by using the base operational strategy discussed above. Regenerative braking was considered in all modes of operation. Figure 7 shows the range when the electric motor is the primary drive component and the heat engine secondary. The range increases as battery capacity increases and electric motor peak power decreases. The variations in range become less sensitive to changes in the electric motor peak power at high peak powers.

Each system package was put through Mission A. The petroleum consumptions per year and the petroleum economies that were evaluated are shown in Figures 8 and 9, respectively. For a given NTHV system package with a battery pack, there is one electric motor and heat engine combination that would minimize the petroleum consumption or maximize the petroleum economy.

The petroleum consumptions for each NTHV system package were then compared with those of the reference ICE vehicle. Figure 10 shows

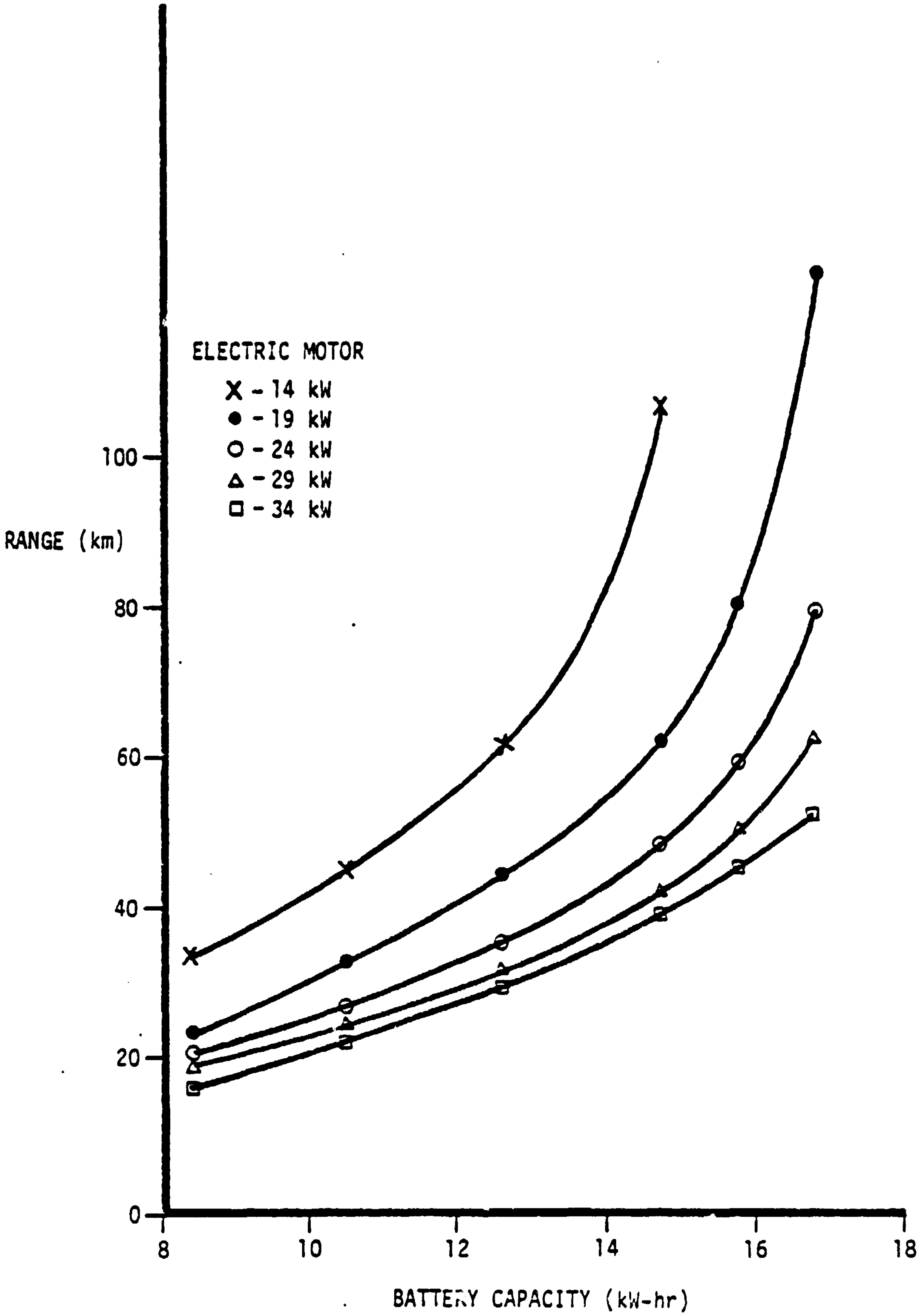


Figure 7. Range for the Electric Motor as the Primary Drive Component for Diffe.ent NTHV System Packages

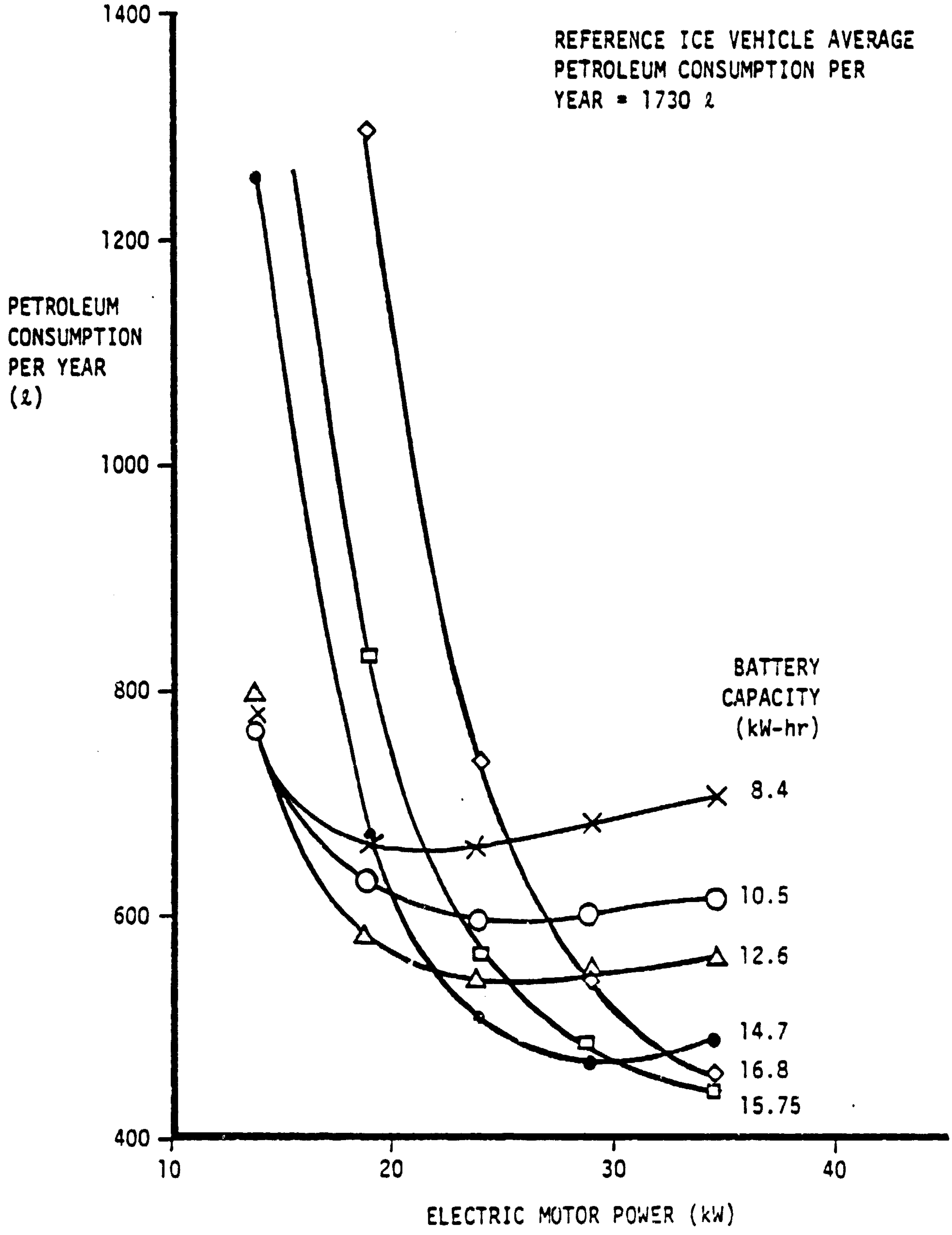


Figure 3. Averaged Petroleum Consumption per Year in Mission A (Reference 1) for Different NTHV System Packages

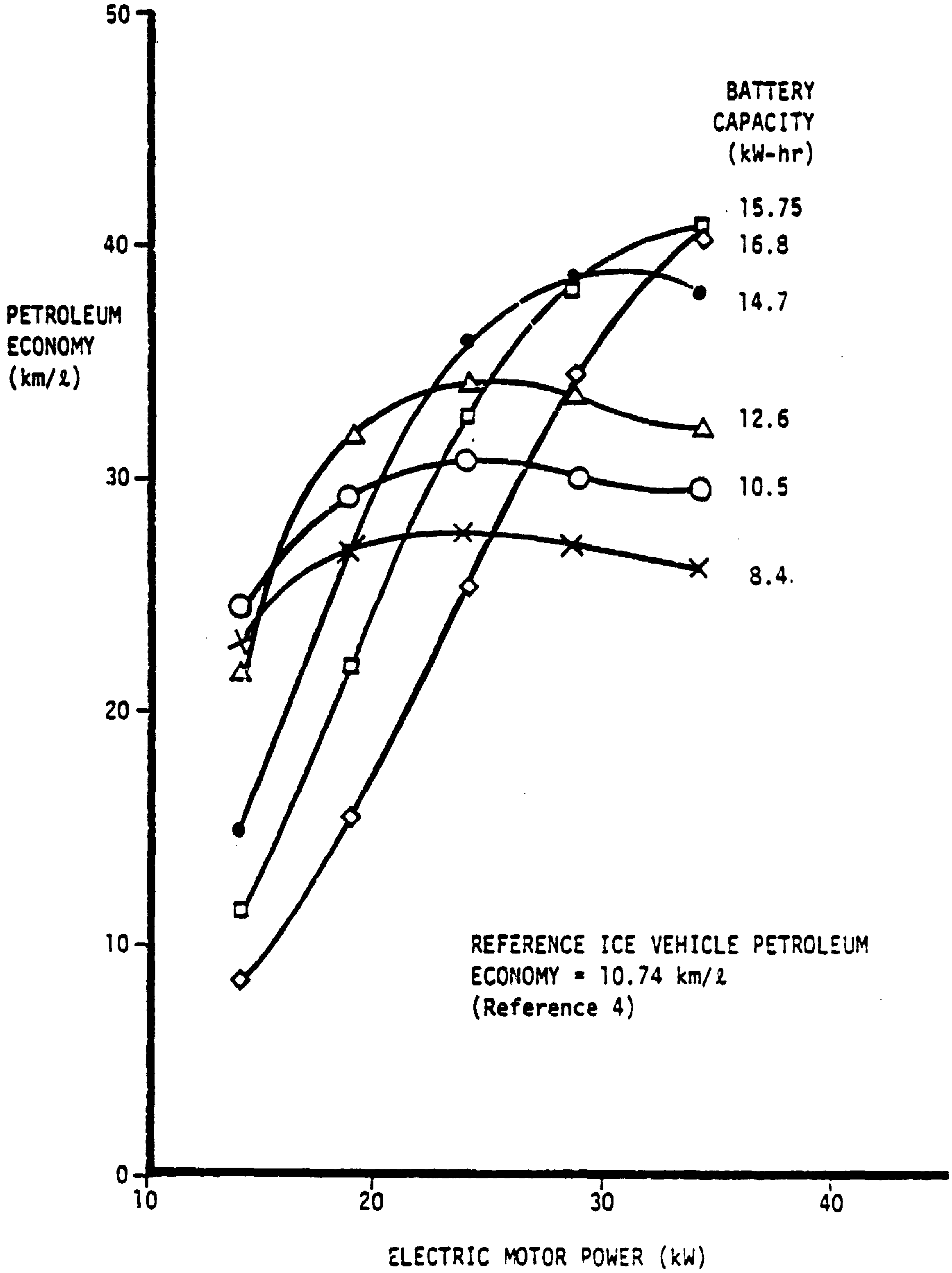


Figure 9. Averaged Petroleum Economy in Mission A (Reference 1) for Different NTHV System Packages

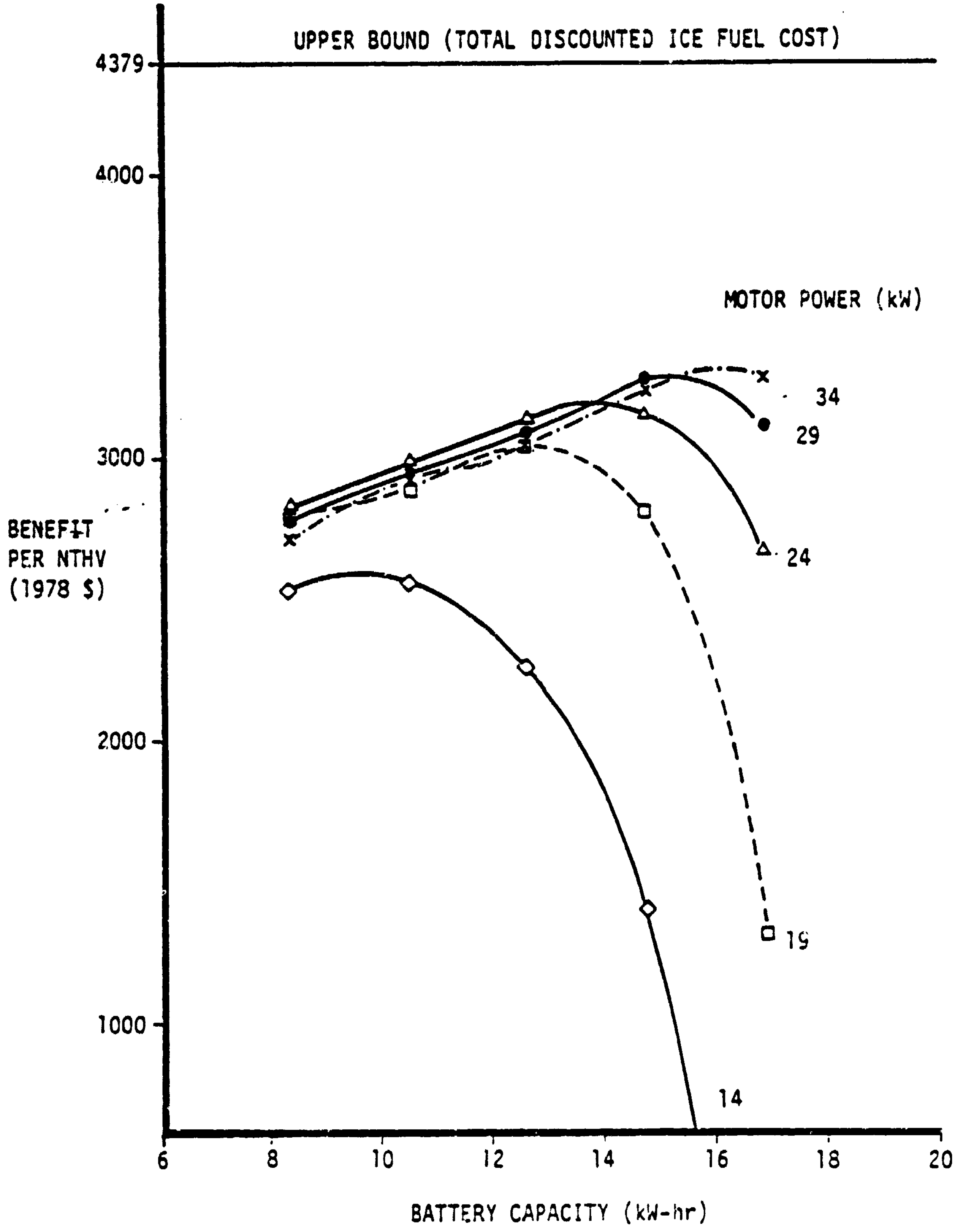


Figure 10. Benefit per NTHV for Different System Packages

the benefit per NTHV as a function of battery capacity for various electric motor peak powers. This figure also verifies that there is a maximum benefit combination of batteries, electric motor and heat engine. As the battery capacity increases, the vehicle weight increases, and the benefit is penalized after the extremum.

As mentioned above, the net benefit per NTHV was found to be negative. This means that the cost of accruing this benefit is always higher than the benefit itself. Figure 11 shows the breakeven petroleum prices as a function of benefit for various NTHV system packages. In this figure each line corresponds to a constant electric motor peak power. The battery capacity increases with increasing breakeven petroleum price; for instance, on the line for the 14 kW electric motor the lowest point corresponds to an 8.4 kW-hr battery capacity. The next higher point corresponds to a 10.5 kW-hr capacity, and so on. Figure 11 sets the relationship between policy making (e.g., accepting a breakeven petroleum price for 1985) and the NTHV system's three major parameters—battery capacity, motor peak power, and engine peak power. The heat engine and motor power combination which maximized the benefit for a given battery package yields the plot shown in Figure 12. The upper portion of the curve is extrapolated to the full-size electric vehicle breakeven petroleum price obtained from Reference 13. Figure 12 verifies that the rate of increase in benefit decreases as the battery capacity increases.

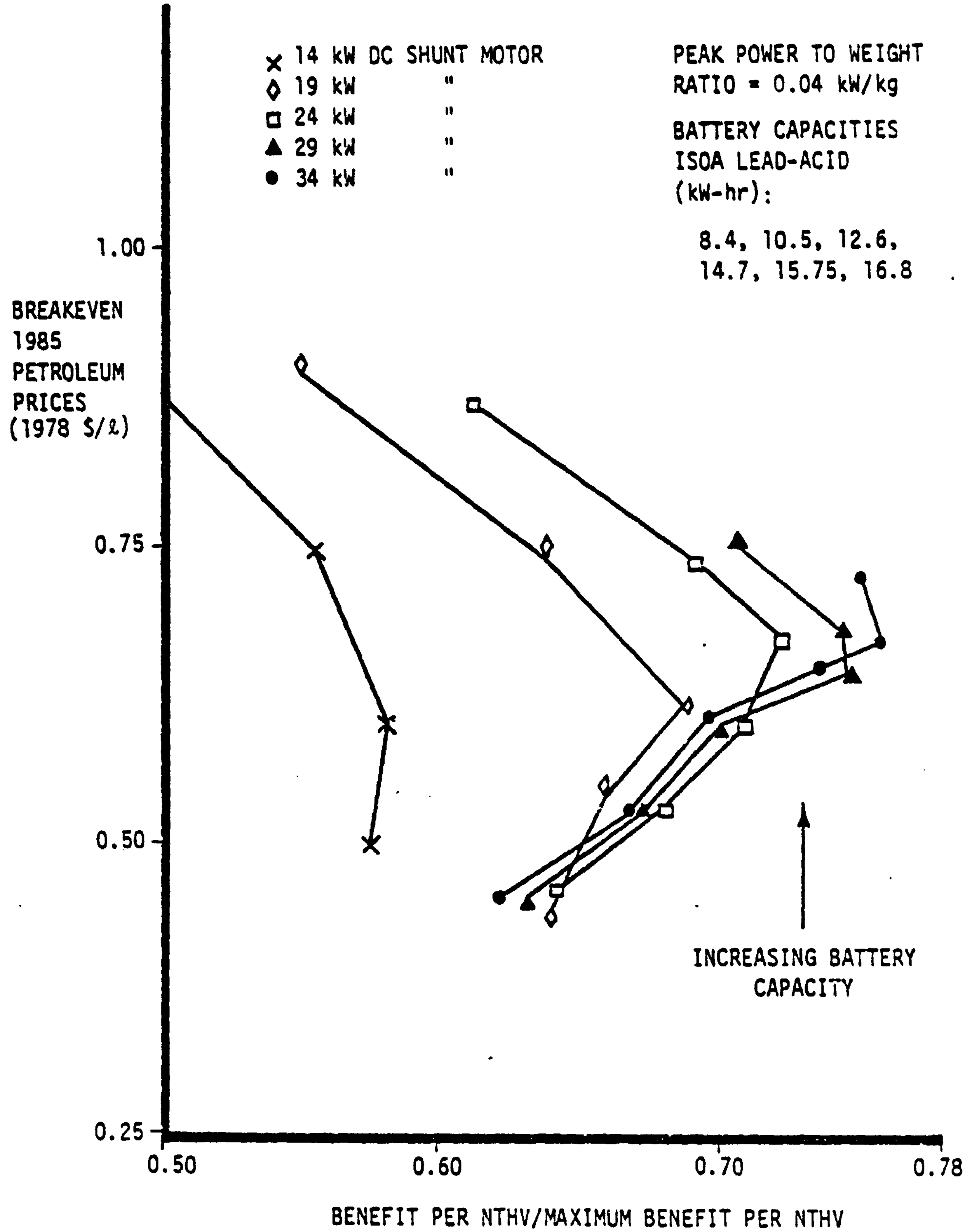


Figure 11. Breakeven 1985 Petroleum Prices at Which the LCC of an NTHV System Package Equals the LCC of the Reference ICE Vehicle

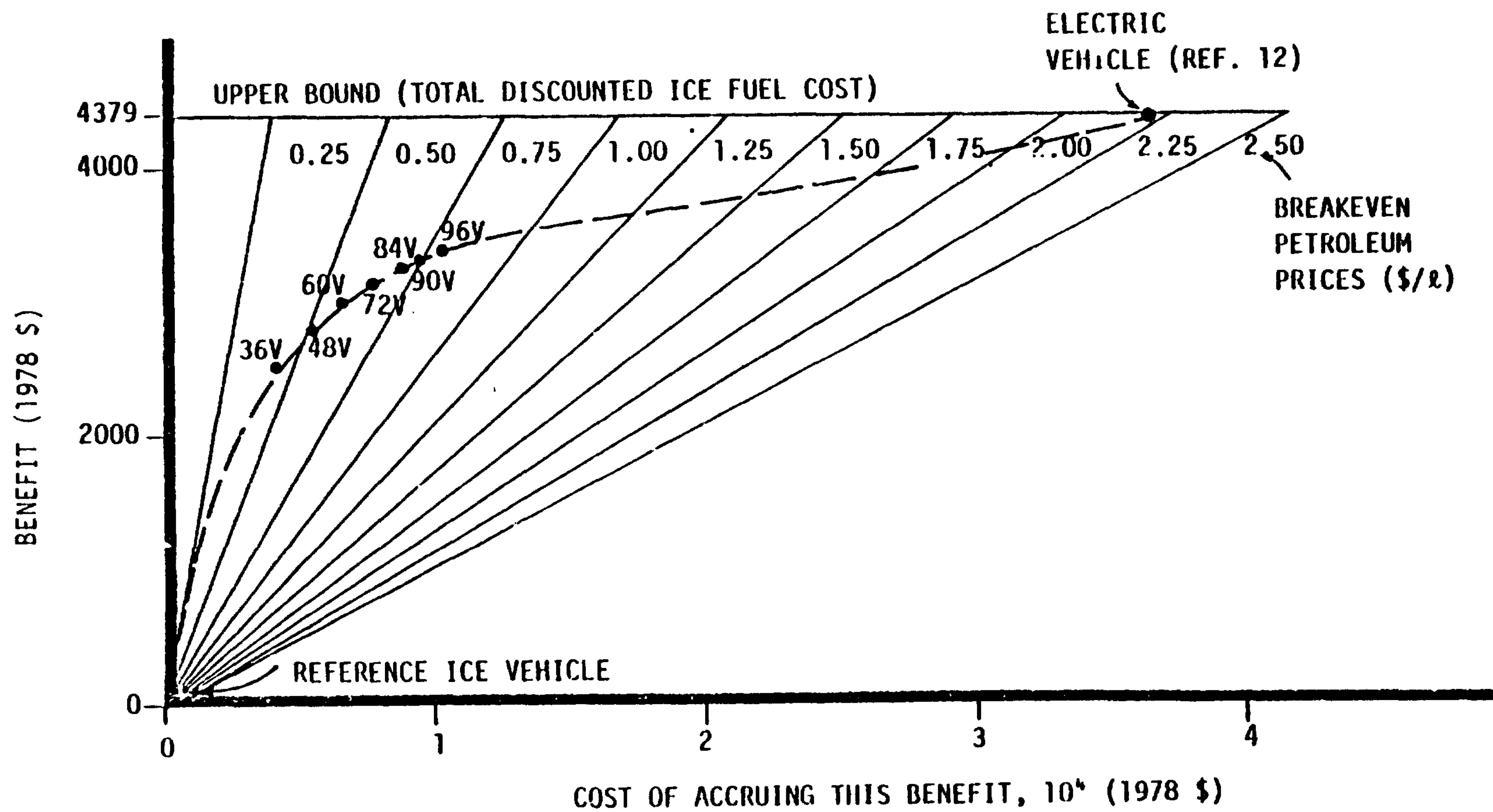


Figure 12. Variation of Benefit with the Cost of Accruing this Benefit where each NTHV Battery Capacity Corresponds to its Maximum Petroleum Savings

SECTION 5

BATTERY TRADEOFFS

It has been widely recognized that the practicality of electric and hybrid vehicles depends primarily on the availability of low-cost long-life batteries with high specific energy and high specific power. The near-term battery alternatives for the hybrid vehicle are effectively limited to the three batteries involved in the Argonne National Laboratoty Near-term Electric Vehicle battery program. The three battery types are the lead-acid, the nickel-iron, and the nickel-zinc. The current statuses and the projected capabilities of these batteries are given in Table 8.

Table 8. Near Term Development Goals for Electric and Hybrid Vehicle Batteries[16]

Battery Type	Specific Energy W-hr/kg	Specific Peak Power	Lifetime Deep Discharges	Cost 1978 $/kW-hr
Lead-Acid				
Current	40	100	800	50
Advanced	60	150	1000	40
Nickel-Zinc				
Current	70	125	200	75
Advanced	90	160	1000	65
Nickel-Iron				
Current	44	130	1500	120
Advanced	60	150	3500	63

Mission A was used for the selection of the battery type for the NTHV. As mentioned above, this mission covers 98.8 percent of all trips. The specific energy and power relationships shown in Figure 13 illustrate the superiority of the nickel-zinc batteries. It is interesting to note that the specific energies of lead-acid and nickel-iron batteries behave similarly and drop drastically at high specific power levels, while the nickel-zinc battery maintains

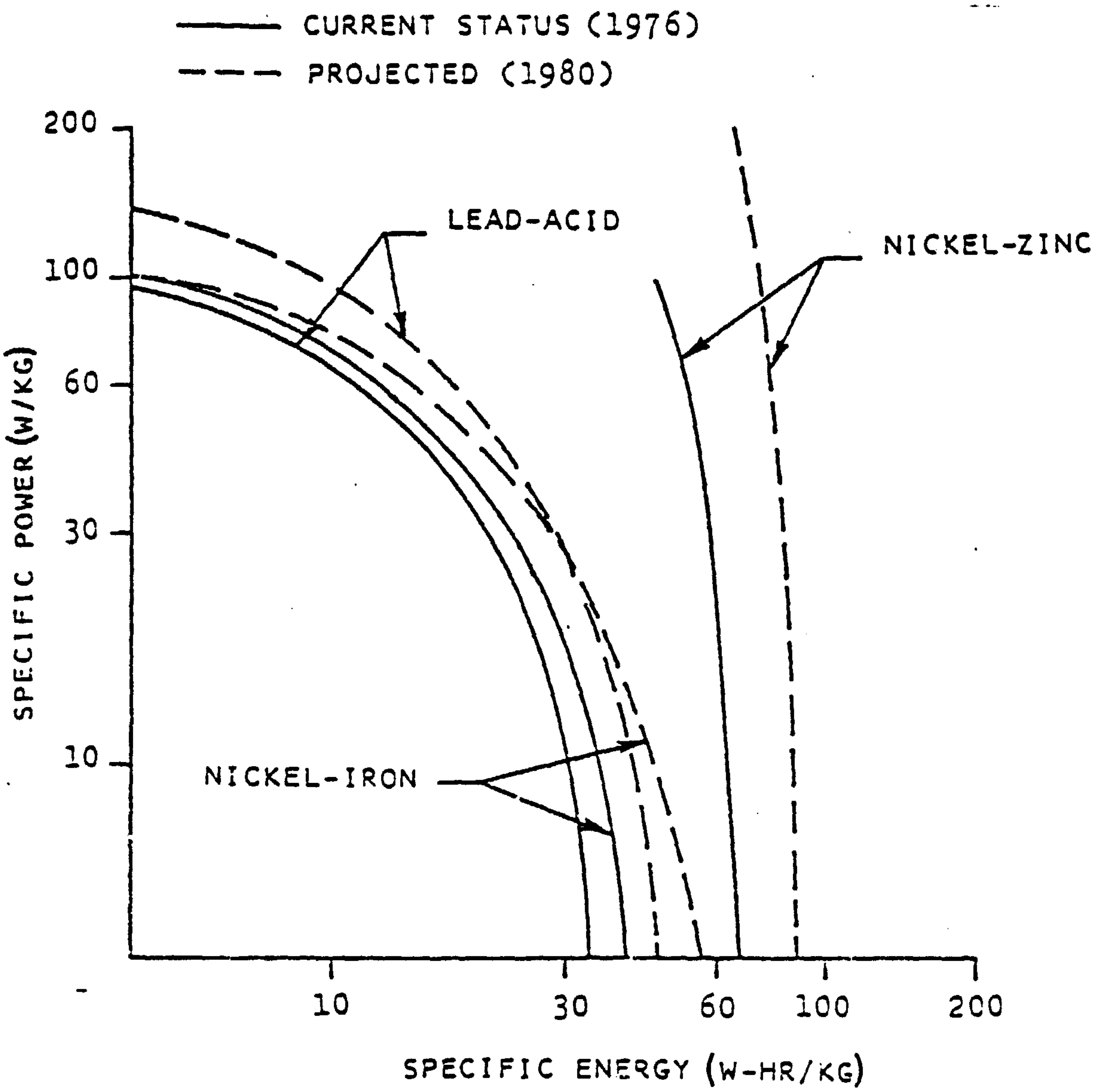


Figure 13. Specific Power Versus Specific Energy for Near Term Battery Candidates

a fairly constant specific energy even at high specific power levels. However, the battery trade-off studies showed that the nickel-zinc batteries are penalized by their short cycle life. The discussion below will show that battery cycle life becomes the governing parameter of battery selection for the NTHV.

We studied the three batteries by using the baseline NTHV system package (12.6 kW-hr [3 hour rate] battery pack, 24 kW D.C. shunt motor, and 48.5 kW turbocharged Volkswagen diesel engine). The battery model used in CARSIM[15] requires the input of an initial state of discharge, final state of discharge, initial open circuit voltage, internal battery resistances, discharge voltage depression constant, battery capacity, and constant coefficients for the battery current-versus-discharge time curve. The input parameters were obtained from up-to-date data on the battery described in References 16, 17 and 18. A typical plot of battery current versus discharge time for nickel-zinc batteries is shown in Figure 14. The discharge voltage and the internal resistances were obtained from the battery-voltage-versus battery-current data at various depths of discharge. A typical plot for nickel-zinc batteries is shown in Figure 15.

The petroleum and electricity consumptions with the electric motor as the primary drive component and with the heat engine as the primary drive component are given in Tables 9 and 10, respectively.

Table 9. Petroleum and Electrical Consumptions for Three Battery Types with the Electric Motor as the Primary Drive Component

Battery Type	FUDC (ℓ/cycle)	FUDC (Δs/cycle)	FHDC (ℓ/cycle)	FHDC (Δs/cycle)	SAE (ℓ/cycle)	SAE (Δs/cycle)
Lead-Acid	0.070	0.2626	0.062	0.3711	0.0	0.0057
Nickel-Zinc	0.031	0.1753	0.015	0.2562	0.0	0.0044
Nickel-Iron	0.034	0.2413	0.022	0.3501	0.0	0.0051

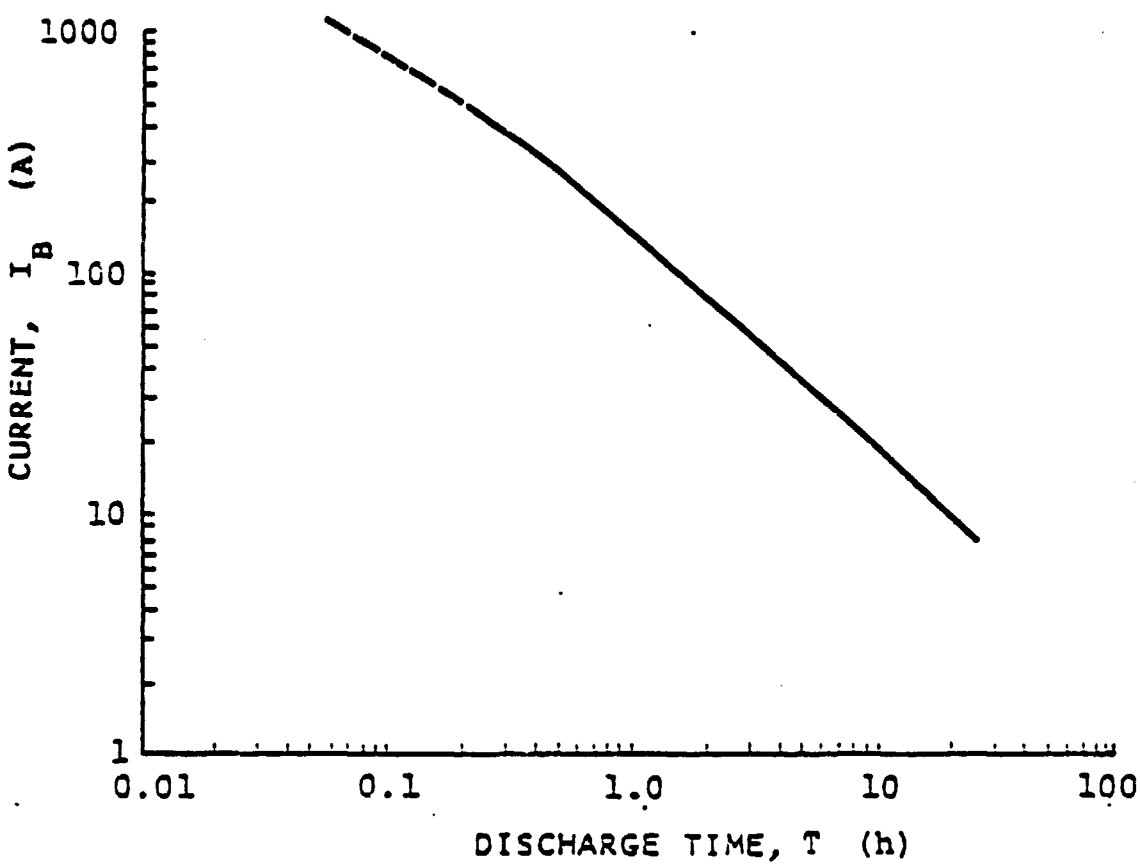


Figure 14. Battery Current Versus Discharge Time for the Nickel-Zinc Battery

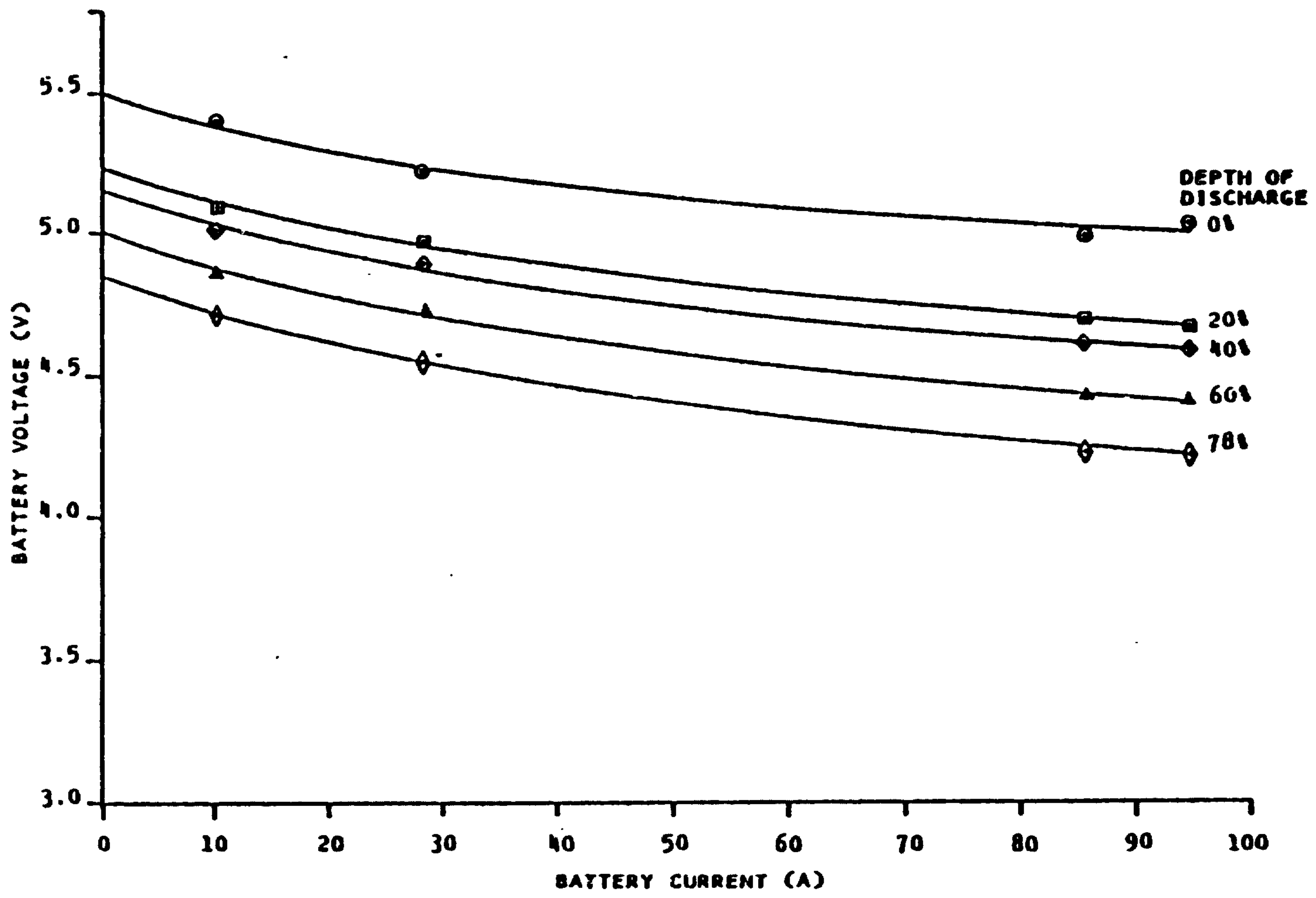


Figure 15. Battery Voltage Versus Current for Various Depths of Discharge, Nickel-Zinc Battery

Table 10. Petroleum and Electrical Consumptions for Three Battery Types with the Heat Engine as the Primary Drive Component

Battery Type	FUDC (ℓ/cycle)	FUDC (Δs/cycle)	FHDC (ℓ/cycle)	FHDC (Δs/cycle)	SAE (ℓ/cycle)	SAE (Δs/cycle)
Lead-Acid	0.795	0.0	0.827	0.0	0.024	0.0
Nickel-Zinc	0.683	0.0	0.748	0.0	0.019	0.0
Nickel-Iron	0.713	0.0	0.765	0.0	0.021	0.0

The results show the advantage of the high specific energy levels possessed by the nickel-zinc batteries. The nickel-zinc batteries are depleted 33 percent less than the lead-acid in the urban driving cycle. The fuel consumption variations in Table 10 are due to the weight differences in the battery packs.

We took the three batteries through Mission A. The results, given in Table 11, again show the impact of the high specific energy levels of the nickel-zinc batteries.

Table 11. Results of Taking the Baseline NTHV System Package Through Mission A for Three Near-Term Batteries

Battery Type	Annual Fuel Consumption (ℓ)	Fuel Economy (km/ℓ)	Annual Electricity Consumption (kW/hr)	Electricity Economy (km/kW-hr)	Electric Range (km)
Lead-Acid	540	34.42	3225	5.77	36.0
Nickel-Zinc	346	53.81	2771	6.71	38.9
Nickel-Iron	447	41.60	3143	5.91	52.4

The results of the economic analysis for the three batteries are shown in Table 12.

Table 12. Results of the Economic Analysis of the Baseline NTHV System Package for Three Near-Term Batteries

Battery Type	Benefit 1978 $	Net Benefit 1978 $	Breakeven Petroleum Price 1978 $/ℓ	1978 $/gal
Lead-Acid	3101	-4567	0.62	2.35
Nickel-Zinc	3539	-10448	0.99	3.75
Nickel-Iron	3321	-2343	0.43	1.62

The cycle lives of the lead-acid, nickel-zinc, and nickel-iron batteries were taken to be 1000, 500, and 2000, respectively.

Table 12 shows that the life cycle costs of the NTHV system packages are quite sensitive to battery cycle life. The high specific energy nickel-zinc battery shows more benefit (or petroleum savings) than the other candidates, but its replacement costs increase the breakeven petroleum price to 0.99 $/ℓ.

If the NTHV packages are evaluated from the consumer's point of view, the battery with the longest cycle life (nickel-iron) becomes the prime candidate for the near-term hybrid vehicle. But if the petroleum savings are maximized, the battery with the highest specific energy, the nickel-zinc battery, becomes the prime candidate. And, if high volume at low cost is considered, the battery that requires no technical breakthroughs (for high volume production), the lead-acid battery, becomes the first choice.

Obviously, battery cycle life is a very significant parameter in NTHV life cycle costs. Figure 16 shows the variation of the net benefit with battery cycle life. If one could develop a battery which has the specific-power-versus-specific-energy profile of the improved state-of-the-art battery, and yet which lasts through the lifetime of the hybrid vehicle, the life cycle costs of the NTHV would be comparable to those of the reference ICE vehicle.

The battery depth of discharge effects the cycle life of the batteries. A typical variation of cycle life with depth of discharge for lead-acid batteries is shown in Figure 17. We studied this relationship, again using the baseline NTHV package. The relation of the battery depth of discharge during a day to the petroleum

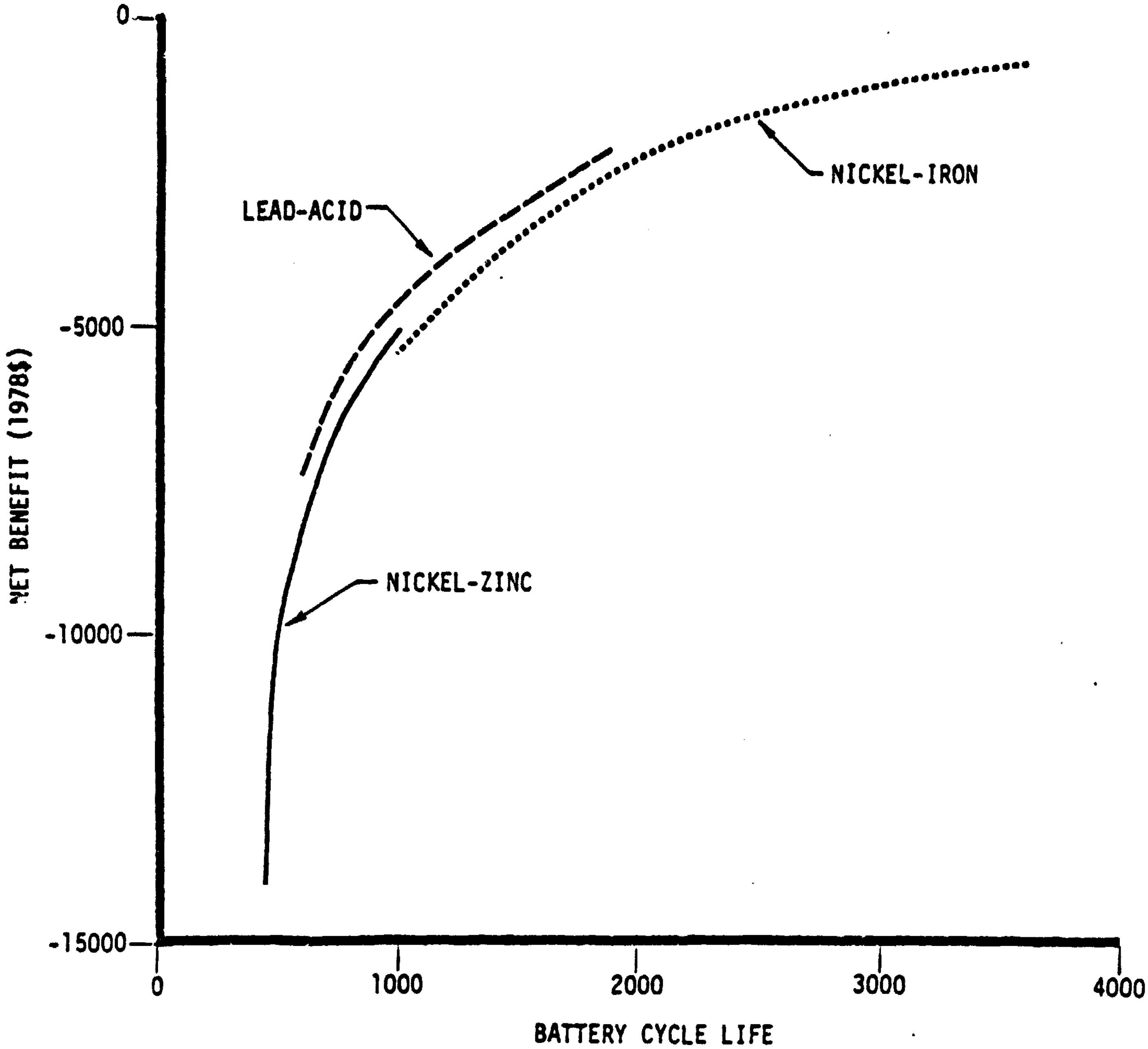


Figure 16. Behavior of Net Benefit as a Function of Battery Cycle Lift

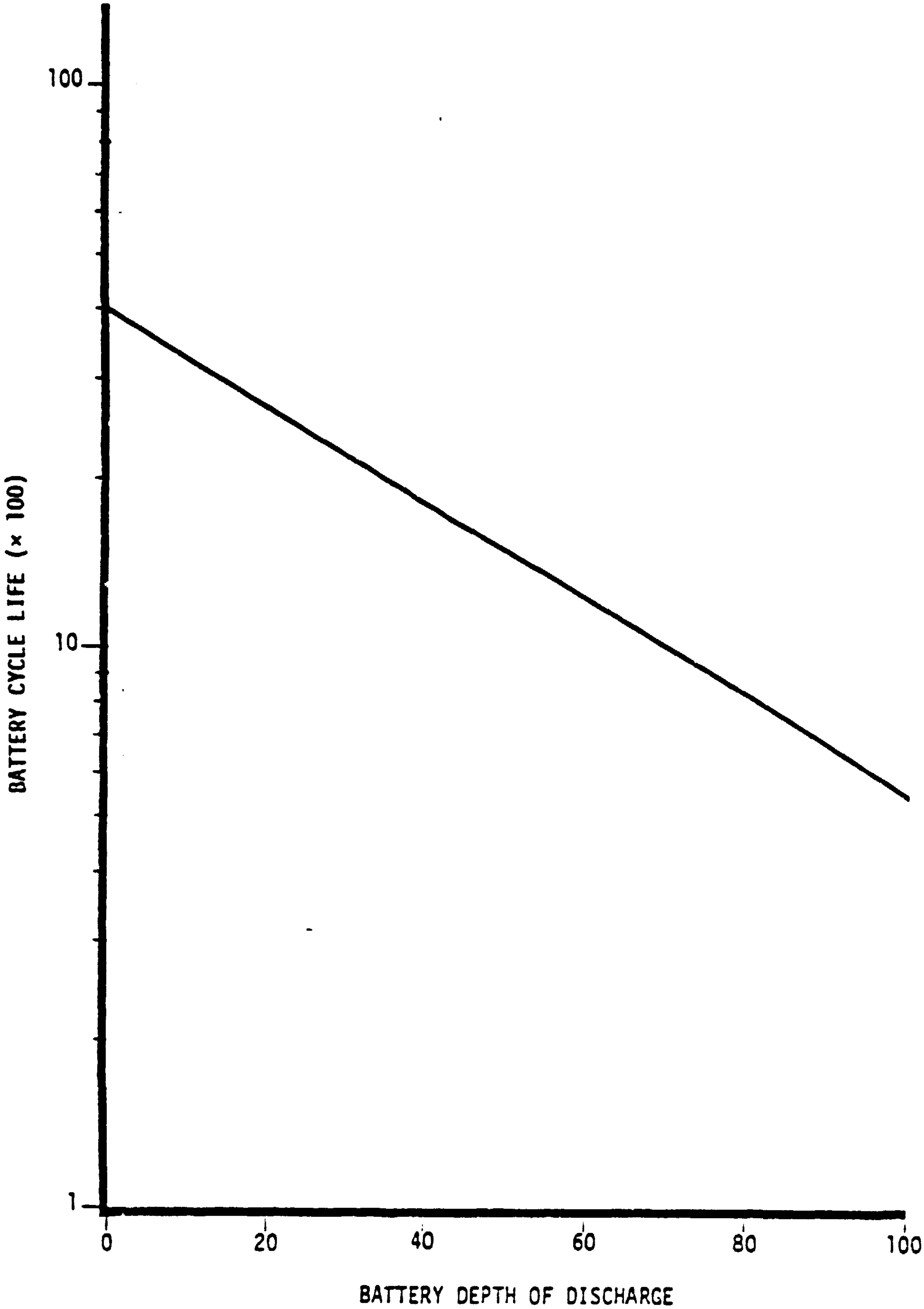


Figure 17. Battery Cycle Life Versus Depth of Discharge for Lead-Acid Batteries

savings is shown in Figure 18. As the final state of discharge during the day decreases, the petroleum savings (and the benefit) decrease. The effect of depth of discharge on electric range for the baseline NTHV is given in Table 13.

Table 13. Variations of the Electric Range with the Battery Depth of Discharge for the Baseline NTHV

Final Battery Depth of Discharge During A Day	Electric Range (km)
0.8	34.2
0.6	25.7
0.4	17.1
0.3	13.6
0.2	8.6
0.1	4.3

The three major parameters for the battery trade-off studies, capacity, cycle life and depth of discharge, have quite different effects on the life cycle costs and on the annual petroleum consumptions. Figure 19 shows the effects of these parameters on the annual petroleum consumption and life cycle cost plane. The battery cycle life is the parameter which minimizes both the petroleum consumption and the life cycle costs. Among the near-term batteries, the nickel-iron seems to have the highest battery cycle life. The Argonne National Laboratory program for nickel-iron battery development is aimed at increasing the nickel-iron battery's specific energy level to 60 W-hr/kg and reducing its costs to 63 $/kW-hr in high production, while maintaining its long cycle life (>2000). This program makes the nickel-iron battery the best candidate for the near-term hybrid vehicle.

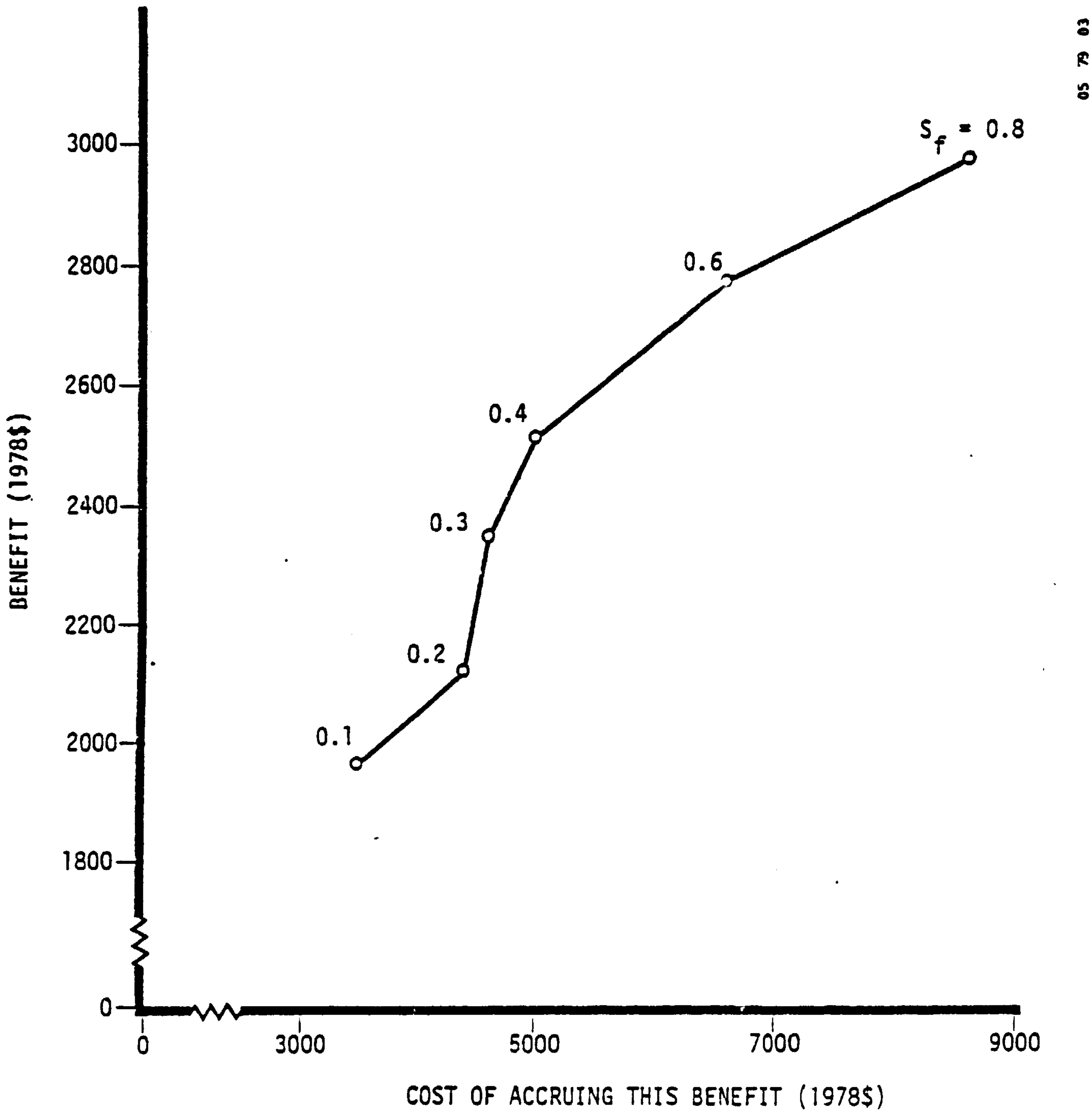


Figure 18. Effect of Battery Depth of Discharge on Benefit and on Cost of Accruing This Benefit

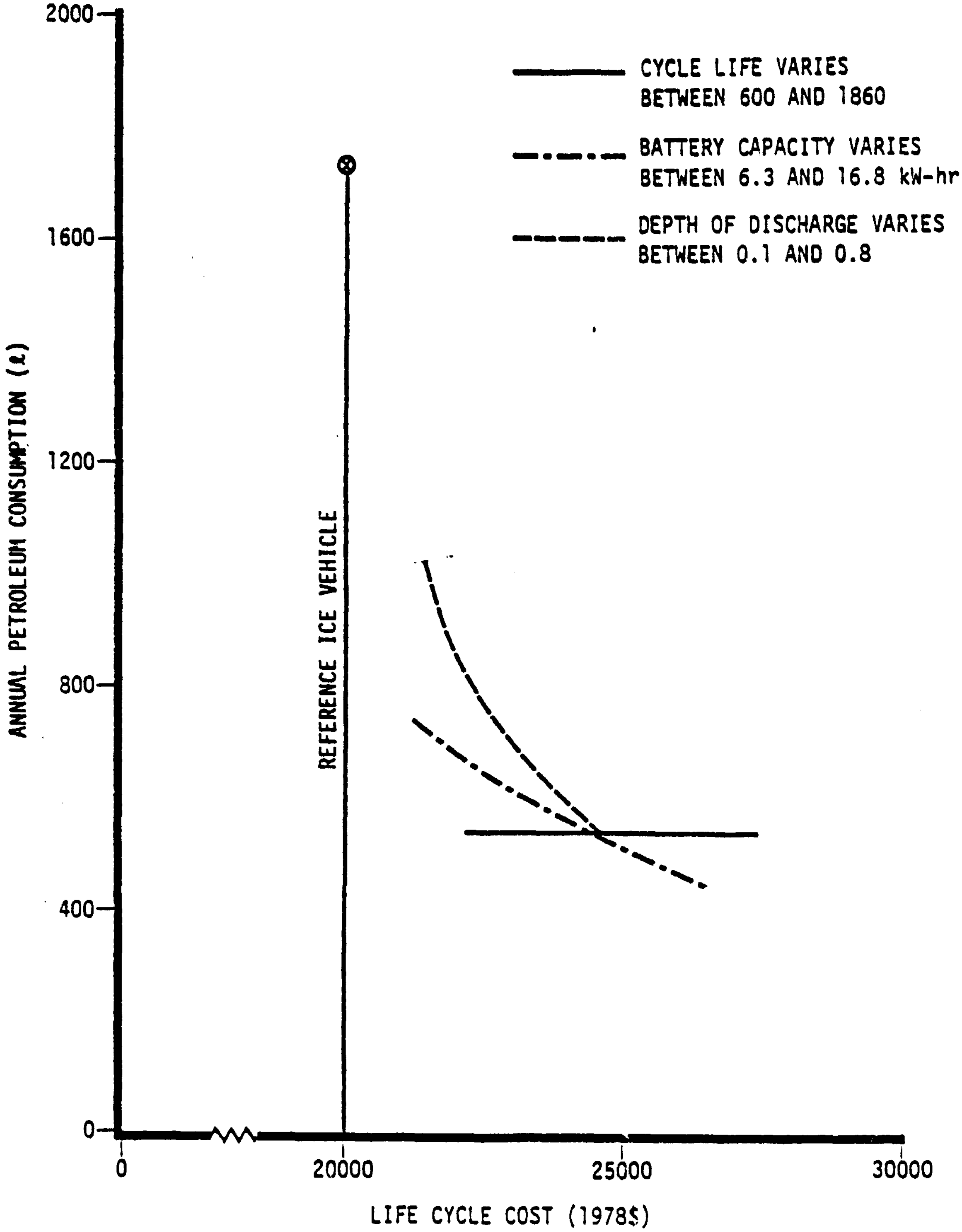


Figure 19. Effects of Battery Capacity, Cycle Life, and Depth of Discharge on Annual Petroleum Consumption and on Life Cycle Cost

SECTION 6

HEAT ENGINE TRADEOFFS

The heat engine was selected by maximizing the net benefit, as discussed in References 3 and 5. We considered four engines that appear to have especially promising specific fuel consumption, weight, cost, and near-term availability. Their specifications are given in Table 14. These engines meet the appropriate emission requirements, have good driveability and durability characteristics, and have very favorable qualitative features for the consumer. The weight gap between the diesel and the spark ignition engines under consideration does not have a great effect on the manufacturing costs and the vehicle performance characteristics. All four engines can be available in the near term in high production volumes and with essentially low unit manufacturing costs.

The engine performance data were obtained from Bartlesville Energy Research Center tests[19-21] and from Reference 22. Figure 20, for instance, shows the fuel consumption curves for the turbocharged Volkswagen Rabbit diesel engine. The engine specifications, the fuel consumption curves and the maximum torque data were inputted into the Minicars hybrid vehicle performance simulation program.

We used the same NTHV system package for the four engines: a 12.6 kW-hr (3 hour rate) improved state-of-the-art lead-acid battery pack, a 24 kW D.C. shunt motor, and a 48.5 kW heat engine. The engines were scaled to 48.5 kW in order to meet the baseline NTHV system package performance requirements. For example, a 96 percent stratified charge Honda spark ignition engine was used for the baseline NTHV system package. Tables 15 and 16 give the petroleum and electricity consumptions with the electric motor as the primary drive and with the heat engine as the primary drive, respectively. The electricity consumptions did not vary more than 10 percent between the different heat engines, and regenerative braking recovered the electrical energy required when the heat engine is used as the primary drive component. The petroleum consumptions varied as much as 38 percent, with the turbocharged Volkswagen Rabbit diesel the lowest.

The baseline NTHV system package was taken through Mission A[1,2] using the four different engines. Table 17 shows that the electricity consumptions were nearly the same, but the petroleum consumptions varied considerably. The diesel engines had better petroleum economies than did the spark ignition engines.

Table 14. Heat Engines Considered in the Trade-Off Studies

Heat Engine	Displacement (cm^3)	Bore (mm)	Stroke (mm)	Compression Ratio	Maximum Power (kW)	Maximum Torque (Nm)	Engine Scale Factor (%)	Scaled Maximum Power (kW)	Scaled Maximum Torque (Nm)
1. Turbocharged Volkswagen Rabbit Diesel	1475	76.5	80.0	23:1	48.5 @ 5000 rpm	119 @ 3000 rpm	100	48.5 @ 5000 rpm	119 @ 3000 rpm
2. Naturally Aspirated Rabbit Diesel	1475	76.5	80.0	23:1	35.8 @ 5000 rpm	79 @ 2500 rpm	135	48.5 @ 5000 rpm	106 @ 2500 rpm
3. Stratified Charge Honda Spark Ignition	1606	73.9	93.0	8:1	50.7 @ 5000 rpm	115 @ 3000 rpm	96	48.5 @ 5000 rpm	110 @ 3000 rpm
4. Volvo Spark Ignition	2130	91.9	80.0	8.5:1	73.8 @ 5200 rpm	141 @ 2500 rpm	66	48.5 @ 5200 rpm	93 @ 3000 rpm

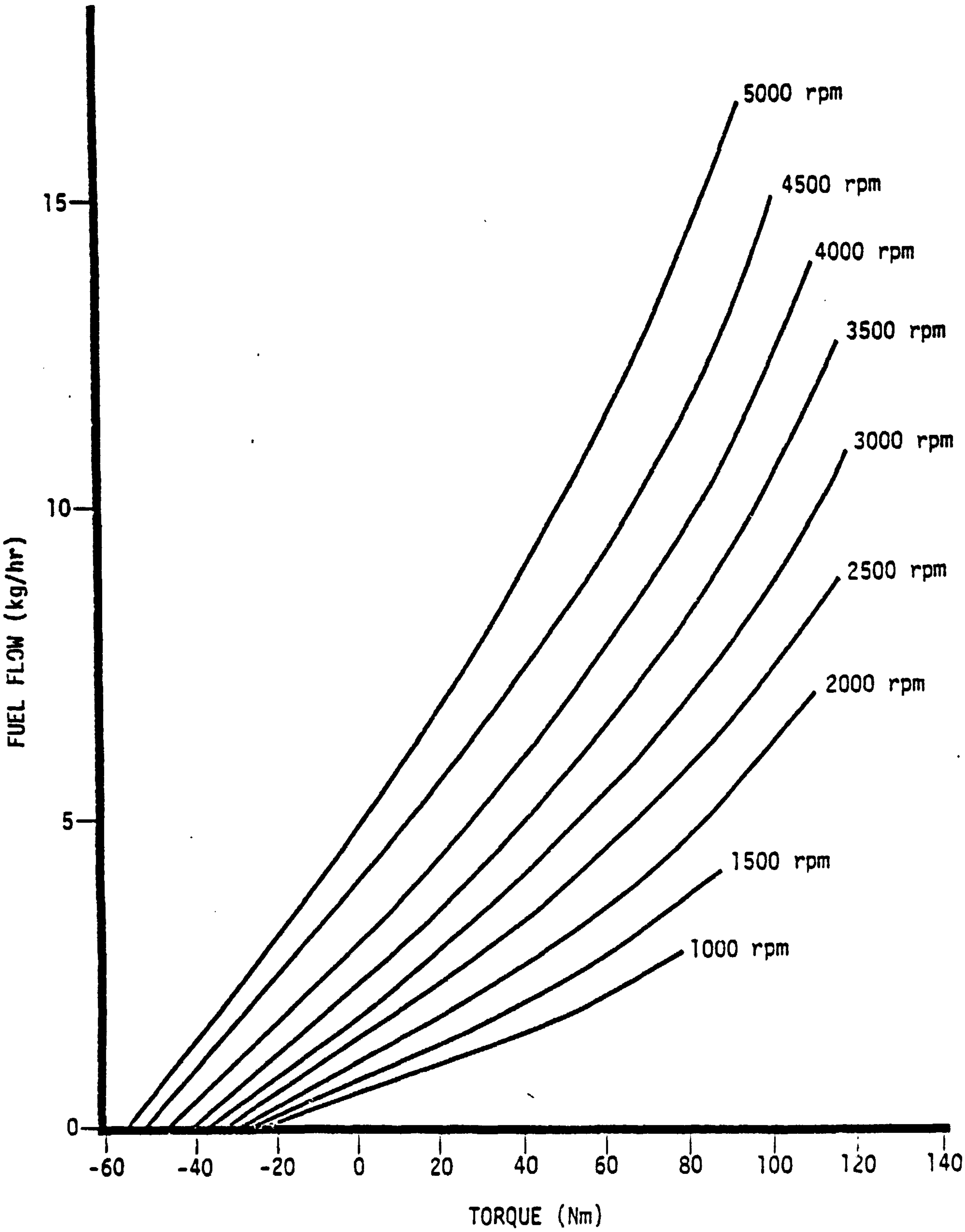


Figure 20. Fuel Consumption Curves for the Turbocharged Volkswagen Rabbit Diesel Engine

Table 15. Petroleum and Electrical Consumptions, with the Electric Motor as the Primary Drive Component

Heat Engine	Engine Scale Factor (%)	FUDC (ℓ/cycle)	FUDC (Δs/cycle)	FHDC (ℓ/cycle)	FHDC (Δs/cycle)	SAE (ℓ/cycle)	SAE (Δs/cycle)
Turbocharged Volkswagen Rabbit Diesel	100	0.070	0.2626	0.062	0.3711	0.0	0.0057
Naturally Aspirated Rabbit Diesel	135	0.079	0.2793	0.085	0.3804	0.0	0.0060
Stratified Charge Honda Spark Ignition	96	0.097	0.2793	0.108	0.3804	0.0	0.0060
Volvo Spark Ignition	66	0.079	0.2787	0.078	0.3813	0.0	0.0064

Table 16. Petroleum and Electrical Consumptions, with the Heat Engine as the Primary Drive Component

Heat Engine	Engine Scale Factor (%)	FUDC (ℓ/cycle)	FUDC (Δs/cycle)	FHDC (ℓ/cycle)	FHDC (Δs/cycle)	SAE (ℓ/cycle)	SAE (Δs/cycle)
Turbocharged Volkswagen Rabbit Diesel	100	0.795	0.0	0.827	0.0	0.024	0.0
Naturally Aspirated Rabbit Diesel	135	0.864	0.0	0.881	0.0	0.027	0.0
Stratified Charge Honda Spark Ignition	96	0.974	0.0	1.013	0.0	0.029	0.0
Volvo Spark Ignition	66	1.101	0.0*	1.093	0.0	0.036	0.0

*Effect of regenerative braking

Table 17. Results of Taking the Baseline NTHV System Package Through Mission A for Four Heat Engines

Heat Engine	Annual Fuel Consumption (liters)	Fuel Economy (km/liter)	Annual Electricity Consumption (kW-hr)	Electricity Economy (km/kW-hr)
Turbocharged Volkswagen Rabbit Diesel	540	34.42	3225	5.77
Naturally Aspirated Rabbit Diesel	604	30.80	3281	5.67
Stratified Charge Honda, Spark Ignition	700	26.57	3281	5.67
Volvo Spark Ignition	739	25.15	3279	5.67

Table 18. Results of the Economic Analysis of the Baseline NTHV System Package for the Four Heat Engines

Heat Engine	Benefit 1978 $	Net Benefit 1978 $	Breakeven Petroleum Price	
			1978 $/ℓ	1978 $/gal
Turbocharged Volkswagen Rabbit Diesel	3101	-4567	0.62	2.35
Naturally Aspirated Rabbit Diesel	2951	-4652	0.65	2.45
Stratified Charge Honda Spark Ignition	2723	-4939	0.71	2.67
Volvo Spark Ignition	2630	-5205	0.75	2.83

The economic analysis results for the baseline NTHV system package with the four different heat engines are given in Table 18. The differences in net benefit are dominated by the differences in the life cycle fuel costs. Of the possible candidates for the NTHV, the turbocharged Volkswagen Rabbit diesel appears to be the best choice.

SECTION 7

ELECTRIC MOTOR, CONTROLLER AND BATTERY CHARGER

7.1 ELECTRIC MOTOR

The complete range of electric drive system candidates for Phase I of the NTHV study was shown in Figure 3-13 of the Technical Proposal for this program[5] (reproduced as Figure 21 here). The focus of the study has now narrowed to several of the most promising candidates.

AC motor drives, both synchronous and asynchronous, were considered for electric vehicle propulsion primarily because of the elimination of the commutator associated with dc motors. These drives have recently found application in rail vehicles. However, they have been excluded from further consideration in the NTHV program because of lack of near term availability.

In recent years the permanent magnet (PM) dc motor has received renewed interest because of the increasing commercial availability of high strength rare-earth permanent magnets. However, PM motors in the power range required for the NTHV are not expected to be available in the near term, and hence are no longer considered drive candidates.

Three DC motor drives looked promising for the near term hybrid vehicle: the series dc motor with armature control, the shunt dc motor with field control and the compound dc motor with field control. These drives have similar manufacturing costs - approximately 1.80 1978$/kg. Therefore these candidates were evaluated primarily on the complexity of control system design, performance and regenerative braking capability.

There are two sorts of armature control on dc motors: contactor and chopper control. The series dc motor with contractor control is widely used in low speed industrial and recreational vehicles. This drive was excluded from consideration for the NTHV because of problems of discontinuous acceleration and lack of regenerative braking capability. The series dc motor operating with field weakening speed control was also eliminated as a candidate because of the difficulties of implementing the field weakening control chopper. The armature chopper will be evaluated in Subsection 7.2.1.

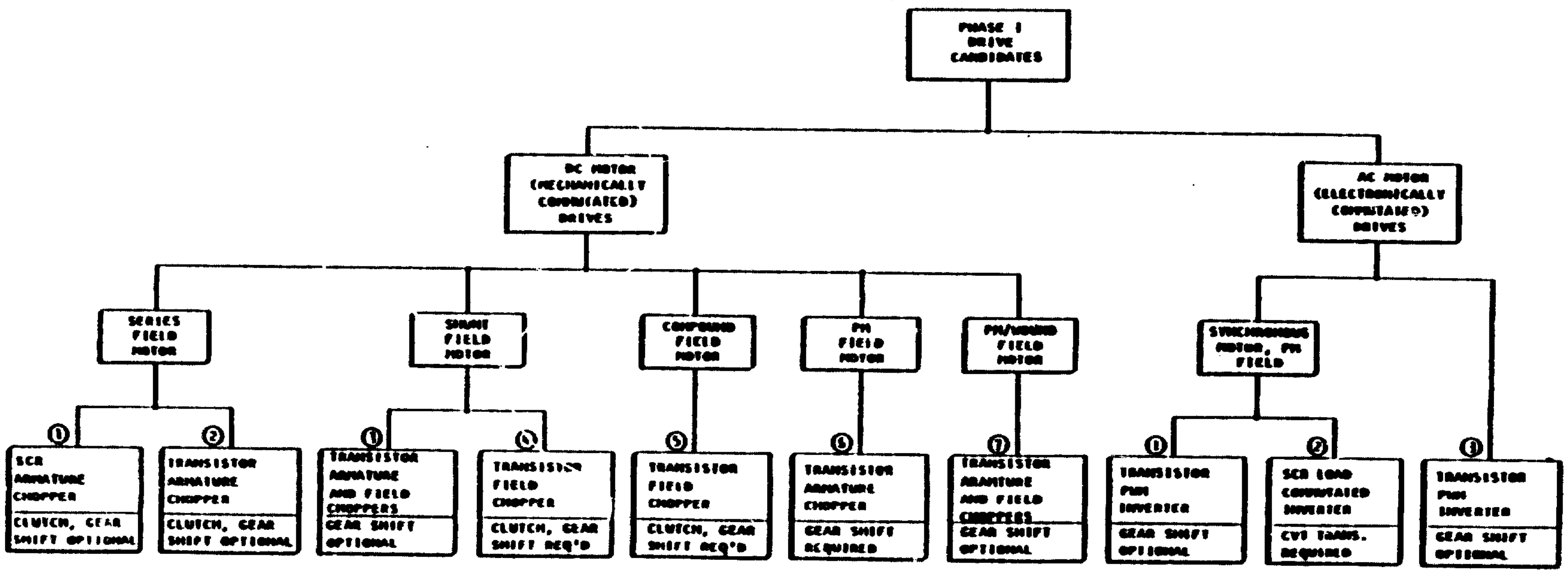


Figure 21. Phase I Candidate Motor Drives

The shunt motor can provide adequate performance with control only by means of a relatively low power field chopper. The need for an armature chopper is negated by using a clutch (or torque converter) to bring the vehicle up to a speed that matches the motor's base speed. The motor is started, with the clutch disengaged, by means of a contactor and a starting resistor. The feasibility of shunt motor propulsion is enhanced by the availability of a variable ratio transmission. The transmission reduces the motor size by reducing the maximum required motor torque (a benefit that applies to series motor propulsion as well). Typical heat engine and shunt motor vs. speed characteristics are shown in Figure 22.

The curve of power vs. speed for the shunt motor extends only down to base speed, indicating unloaded operation only below that speed. Power output is constant up to the speed N_1 (typically 4600 RPM). This is obtained by reducing the field current and flux to maintain the motor back EMF approximately equal to the battery voltage. At that speed, magnetic stability considerations do not permit further reduction of flux, and power output decreases with additional increases in speed.

The control of the speed and power of dc electric motors for vehicle propulsion systems is generally accomplished by varying the effective voltage applied to the armature, by varying the effective motor field excitation, or by a combination of the two.

Armature voltage control affects the motor speed at a given load nearly in proportion to the effective value of armature voltage — that is, the applied voltage less the resistance drop.

Since motor speed is an inverse function of the effective field magnetization or flux, the motor speed and power can also be controlled by varying the field excitation. This can be readily accomplished in either the shunt or compound type of motor by controlling the relatively low level current used to excite the shunt field coils. Speed ranges on the order of 2:1 to 3:1 can be obtained with this type of control. The limitations to this speed range are caused by the saturation of the magnetic path of the machine at the maximum field, or low speed end, and by commutation stability and pole face polarity reversal effects at the high speed, or weak field end. These limitations are caused by the distorting effects of armature reaction, or cross-magnetization, which effectively distorts or weakens the effective main field as a function of armature current. In general terms, a field excitation of at least 40 percent of the effective armature ampere turns for

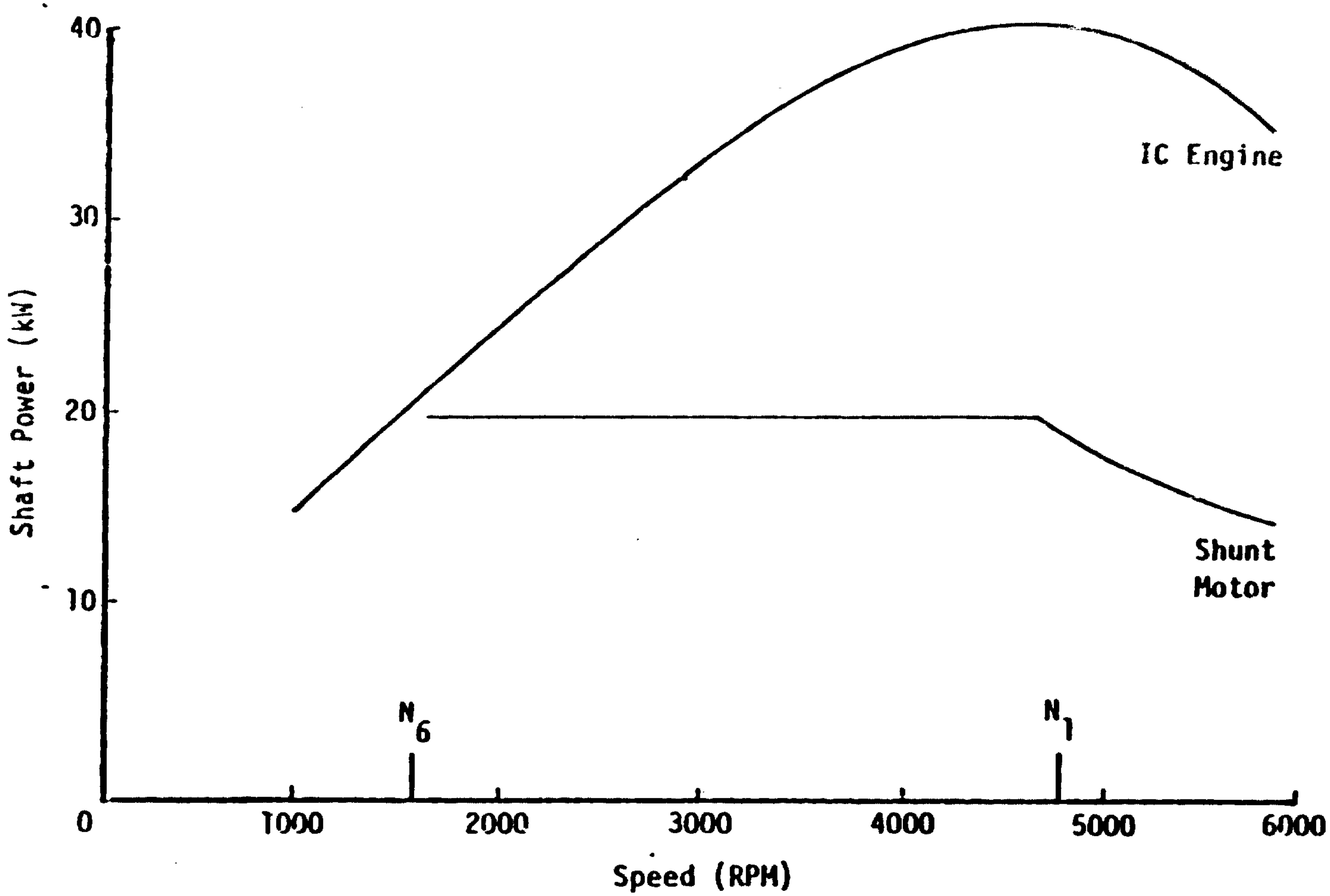


Figure 22. IC Engine and Shunt Motor Characteristics

interpole motors, and at least 80 percent for non-interpol motors, must be maintained for the maintenance of proper motoring action.

With the compound motor this can be inherently produced by providing just sufficient series main field turns to yield this minimum value of field excitation. This is because, as stated above, the minimum value of field excitation is a percentage of armature excitation (is proportional to armature current). Accordingly, when the series winding is designed to supply this minimum excitation requirement, the shunt field current can be varied from maximum to zero over the load range of the motor without loss of commutation stability due to armature reaction.

In straight shunt field motors, where there is no armature current actuated series field winding, the field current controller must also be designed to provide the required minimum value of field excitation in order to control armature reaction effects at all times and load conditions. With motors that are subject to sudden speed changes or transient loads, the required field excitation changes may have to be accomplished very quickly, to prevent the motor from entering an unstable commutation range. Hence the control circuitry may need to include anticipatory, or closed servo loop, field forcing capability.

It should be noted that in either motor design, shunt or compound, the minimum practical field magnetization (and hence maximum effective power output) will be essentially the same - that is, as governed by the armature reaction problem. Therefore, given otherwise similar motor designs, there is no power advantage to be obtained from eliminating the series field. The total field excitation power requirement also does not change, for it does not matter whether this is obtained by shunt or series field coils. However, the straight shunt motor imposes a more complex field current control requirement in order to meet the minimum field excitation needs of the motor. It is only the ease of designing the overall motor, engine and transmission control system that emphasizes advantages of the compound over the shunt motor.

7.2 MOTOR CONTROLLER

The two possible control modes for a compound motor are field voltage control and combined armature and field control. Armature current control only (with the field connected directly to the battery) is not a viable option because of the wide fluctuation of battery voltage.

7.2.1 Armature Voltage Control

Several facts must be borne in mind when evaluating the practicality of armature voltage control for relatively large and high performance vehicles (such as the NTHV). First, the size and cooling requirements of an armature controller are determined largely by the maximum armature current. This current is high, at approximately 300 Adc, and is on the order of that of a rapid transit car propulsion motor (which powers, in sets of four, a vehicle having a loaded weight of approximately 50 times that of the NTHV). This current level is dictated by the relatively low voltage of the battery. The voltage is set by the availability of existing designs of cell assemblies and the maximum number of cells that can operate in series with adequate reliability.

The armature current will be higher still, and the motor size increased still further, if a variable ratio transmission is not provided to reduce the maximum motor torque requirement. A recent article[23] describes some of the operating limitations attendant to the use of a constant ratio transmission EV drive. For example, the high current required to negotiate a 5 percent grade permits vehicle operation for only 20 seconds before commutator overheating occurs.

Either thyristor (SCR) or transistor switches can, in principle, be used to implement an NTHV armature chopper. The transistor chopper can also utilize conventional bipolar transistors, Darlington bipolar transistors, or field effect transistors. The SCR chopper, unlike the transistor chopper, does not require any advance in device technology to obtain adequate drive performance. However, the inherent complexity of the SCR chopper required to meet the NTHV requirements appears to make this approach economically impractical.

7.2.2 Transistor Armature Voltage Control

Conventional bipolar transistors have the greatest power handling capability per unit area of silicon because of the relatively low on-state voltage. However, the transistor gain is low (typically less than 10) at high collector current levels, and this leads to high base current requirements and complex drive circuitry. The Darlington transistor incorporates a driver transistor packaged with the main transistor. This increases the gain to typically several hundred or more but reduces the current handling capability by reducing the amount of silicon allotted to the main transistor and by increasing the saturation voltage and on-static losses.

paralleling is required for either conventional or Darlington bipolar transistors to obtain the 300 A rating required for NTHV drive motor control. Significant derating is necessary because of the tendency of the transistors to share current unequally, a tendency which is aggravated by the negative temperature coefficient of saturation voltage. This characteristic causes the warmest transistor to take an increased share of the total current, raising its temperature still further.

A less apparent problem in paralleling bipolar transistors concerns the inevitable mismatch in turnoff time, which causes the last paralleled transistor to turn off to conduct all of the load current. Again, this effect is aggravated by the temperature dependence of turn-off time which causes increased turn-off time, (and increased conduction of the total current for a longer time) as the transistor temperature increases. Turn-off time mismatch also aggravates the problem of secondary breakdown in bipolar transistors. Secondary breakdown is a failure mode which is caused by the tendency for collector current to crowd into a small portion of the normal current path under the influence of high blocking voltage. This causes localized heating, which can produce either gradual device degradation or catastrophic failure.

The Metal Oxide Semiconductor Field Effort Transistor (MOSFET) has emerged within the last three years as a potential replacement for the bipolar transistor power switch, This is due to three inherent advantages:

- Essentially infinite dc power gain
- Positive temperature coefficient, permitting stable paralleling
- No secondary breakdown characteristic.

The state of the art in power MOSFET technology is represented by the International Rectifier IRF100, rated at 80 V and 16 A, and the IRF306, rated at 350 V and 5 A. Both of these devices are available in TO-3 packages. For the present application, a voltage rating of 160 V is required. Assuming that a modified version of the IRF100 design could be targeted for 160 V, one would expect the current rating to be reduced to (80/160) 16 = 8 A. To meet the 300 A requirement for a NTHV armature chopper, a total of 300/8 $\doteq$ 38 paralleled devices would be required. This is an impractically large number and indicates that significantly more progress must be made in power MOSFET technology before the device can be considered for application to armature choppers. However, the MOSFET does appear promising for use in field choppers; this subject is discussed in Subsection 7.3.1.

7.2.3 SCR Armature Voltage Control

The SCR switch in armature chopper application imposes none of the power handling limitations discussed above for transistor switches. This is because of the tendency of anode current in the SCR to force the device harder into conduction, thus maintaining a low on-state voltage even in the presence of high fault currents. By way of contrast, collector current in the transistor tends to force the device out of conduction if collector current exceeds the rated value by even a small amount. This gives the transistor a very small overload capacity relative to the SCR.

Much of the complexity of the SCR chopper stems from the inductor-capacitor (LC) circuitry and the auxiliary SCRs and diodes required to turn off the main SCR. This complexity is acceptable in high powered (and expensive) vehicles, such as electric locomotives and rapid transit cars. In such applications, the high voltage, as well as the high current, capability of the SCR is fully utilized.

Additional complexity is introduced into the SCR chopper by the requirement for regenerative braking. This necessitates either the use of additional semiconductor and LC elements to perform the braking function, or the use of contactors to change the circuit connections in the braking mode. The former approach gives poor utilization of the electronic components, while the latter introduces frequently cycling contactors — which reduce the overall reliability of the drive system. Figure 23 illustrates a typical SCR chopper. (This figure does not include the details of the field chopper which is required to buffer the field winding from the varying battery voltage and which may also be used to extend the motor speed range by field weakening.)

The components in Figure 23 are

F = Fuse
K1 = Battery disconnect contactor
K2 = Chopper bypass contactor
K3 = Motor/brake mode transition contactor
D1 = Free wheel diode for motoring
D2 = Free wheel diode for braking
F1 = Compound motor series field
F2 = Compound motor shunt field

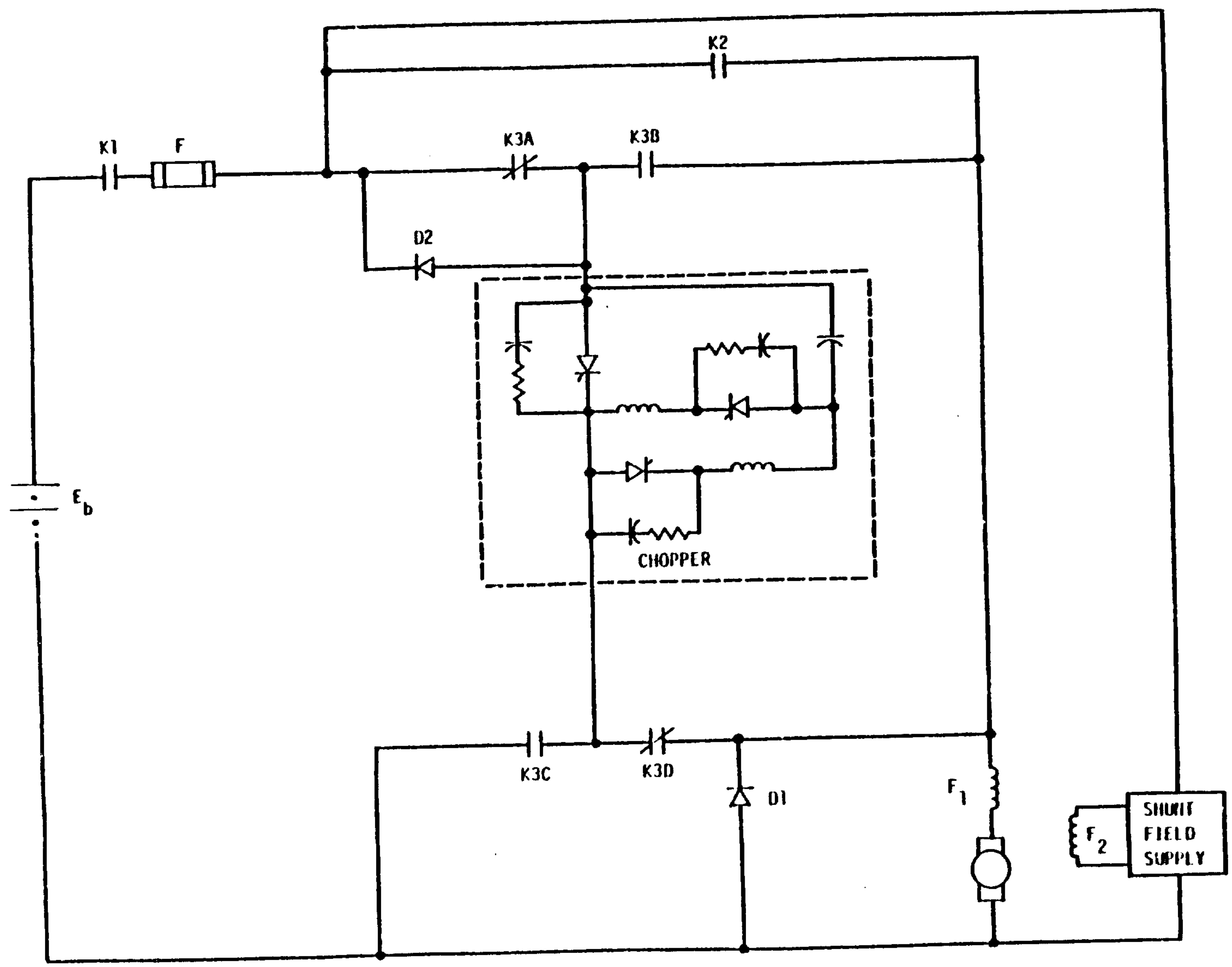


Figure 23. Typical SCR Armature Chopper

The chopper is composed of one main and two auxiliary SCRs, two commutating inductors, a commutating capacitor, three RC dv/dt suppression networks, and three SCR gate driver circuits.

Quotations were obtained on chopper components for production at a rate of 1000 choppers per year. The resulting production cost breakdown for a 300 A regenerative armature chopper is given in Table 19.

Table 19. Regenerative Armature Chopper Production Cost Breakdown

Contactors (3)	$203.00
SCRs (3)	115.00
Diodes (2)	50.00
Commutating capacitor (1)	8.50
Commutating inductors (2)	16.00
Gate drive components	25.00
dv/dt resistors & capacitors	35.00
Heat sink extrusions	25.00
Miscellaneous parts	35.00
Manufacturing labor	200.00
Total Manufacturing Cost	$712.50

In motor control manufacturing for a competitive market a 100 percent markup on manufacturing cost is typical. This markup makes the price of the armature chopper $1,425.00. For high mass production (say 100,000 units per year) we estimate the cost to be approximately 20 percent lower. Still, this cost analysis indicates that the armature chopper approach to electric vehicle control is not economically viable. Together with the relatively high on-state and switching losses inherent in using solid state switching controls in low voltage drive systems, this fact led to the selection of the field controlled motor as the baseline electric propulsion system for the NTHV.

7.2.4 Motor Field Control

Motor speed can be controlled over a speed range of up to 3:1, depending on the motor's magnetic circuit design. This speed range can be multiplied by the range of the transmission's shift ratios to provide an acceptable vehicle speed range. The field controlled motor has a minimum (base) speed which, for a given design, is set by the battery voltage. In vehicle operation, the declutched motor is started with contactors and a current limiting resistor. The clutch (or torque converter) is then slipped until the vehicle reaches the motor's base speed in the lowest gear. This operation also takes place for ICE propulsion, except that the idle speed of the engine may be less than the base speed of the electric motor.

Both bipolar transistors and MOSFET transistors are practical for use in the field chopper. We have selected the MOSFET approach because it permits a simpler circuit design and is potentially more reliable (for the reasons discussed in Subsection 7.2.2). The rapid improvements in MOSFET technology now taking place promise to reduce or eliminate the present requirement for parallel operation.

The performance requirements for the motor field controlles are given in Table 20. Figure 24 is a block diagram of the field controller. Timing diagrams for the controller are shown in Figure 25. For simplicity, we have assumed zero initial field current and a constant command signal. The first pulse from the clock generator following application of the clock enable signal sets of Q output of the R-S flip-flop high, turning on the power switch. Battery voltage is then applied to the field winding and current increases at an initial rate of E_b/L_f amperes/second. The current feedback signal developed in the current sensor is subtracted from the command signal. When this difference becomes negative, as it does in Figure 25 after the third clock pulse, the comparative output goes high, resetting the flip-flop output to zero and opening the power switch. Current in the field winding then decays exponentially through the free-wheeling diode (FWD) according to the time constant L_f/R_f. At the instant of the fourth clock pulse, the flip-flop is reset and the power switch is closed to re-apply battery voltage to the winding, causing current to again rise to the commanded level.

The circuit diagram of the motor field controller is shown in Figure 26. The low level control components (consisting of resistors, capacitors and several multiple operational amplifier and logic gate integrated circuits) can be packaged on a 3 x 5 inch p.c. board. The three paralleled MOSFET transistors would then be mounted on a common heat sink together with the 15-volt regulator and 40 mOhm shunt resistor.

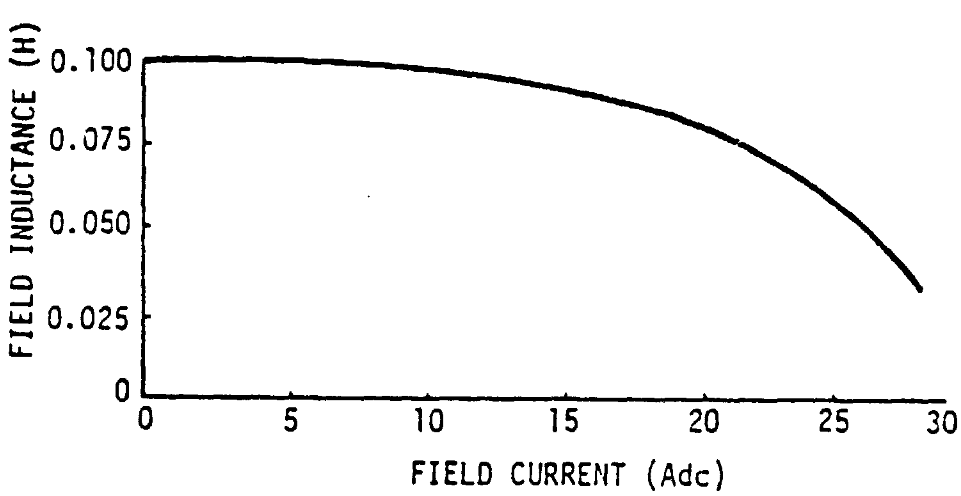
Table 20. Performance Requirements
for the Motor Field Controller

Input Voltage. The MFC will be designed to operate over an input voltage range of 50 to 95 Vdc. This covers the conditions of maximum discharge to maximum charge.

Load Impedance. The MFC load impedance is the motor field winding which can be described as an equivalent series resistance and inductance.

The load resistance has a nominal value of 1.65 ohms at a winding temperature of 20°C and varies from 1.40 ohms at -20°C to 2.50 ohms at 150°C.

The incremental load inductance has a nominal value of 0.10 H at low current and follows the saturation curve shown below at higher current.



Transfer Function. The MFC provides a steady state output current proportional to an input dc command signal. The controller trans-conductance factor is 2.0 A/V.

Table 20, continued

Input Signals. Three MFC input signals are available. These are

- Current command analog signal; 0 to 10 Vdc. From 2.0 kΩ source impedance.
- Field forcing discrete signal; normally 0 Vdc, 15 Vdc for field forcing command. From 2.0 kΩ source impedance.
- Mode control signal; 0 Vdc for standby mode, 15 Vdc for operate mode.

Output Current. The maximum MFC output current under any condition of battery voltage or field winding temperature is 20 Adc.

Output Power. The maximum MFC continuous power output varies with field winding temperature from 550 W at -20°C to 1000 W at 150°C.

Output Voltage. The maximum MFC continuous output voltage varies with winding temperature from 28 Vdc at -20°C to 50 Vdc at 150°C.

Field Forcing. Higher than rated voltage is applied to the field winding for a period of less than 0.5 second to provide rapid motor deceleration when changing gears. In the field forcing mode, full battery voltage (less any switching element voltage drop) is applied to the field winding.

Electromagnetic Interference (EMI). EMI from the MFC must be limited to a level which does not interfere with the vehicle electronic systems.

Efficiency. The efficiency of the MFC must be greater than 90 percent at maximum output current and greater than 80 percent at 50 percent output current.

Packaging. The MFC will be housed in a sealed package with conduction cooling to the vehicle mounting surface. The temperature range of the MFC mounting surface is -20°C to +65°C.

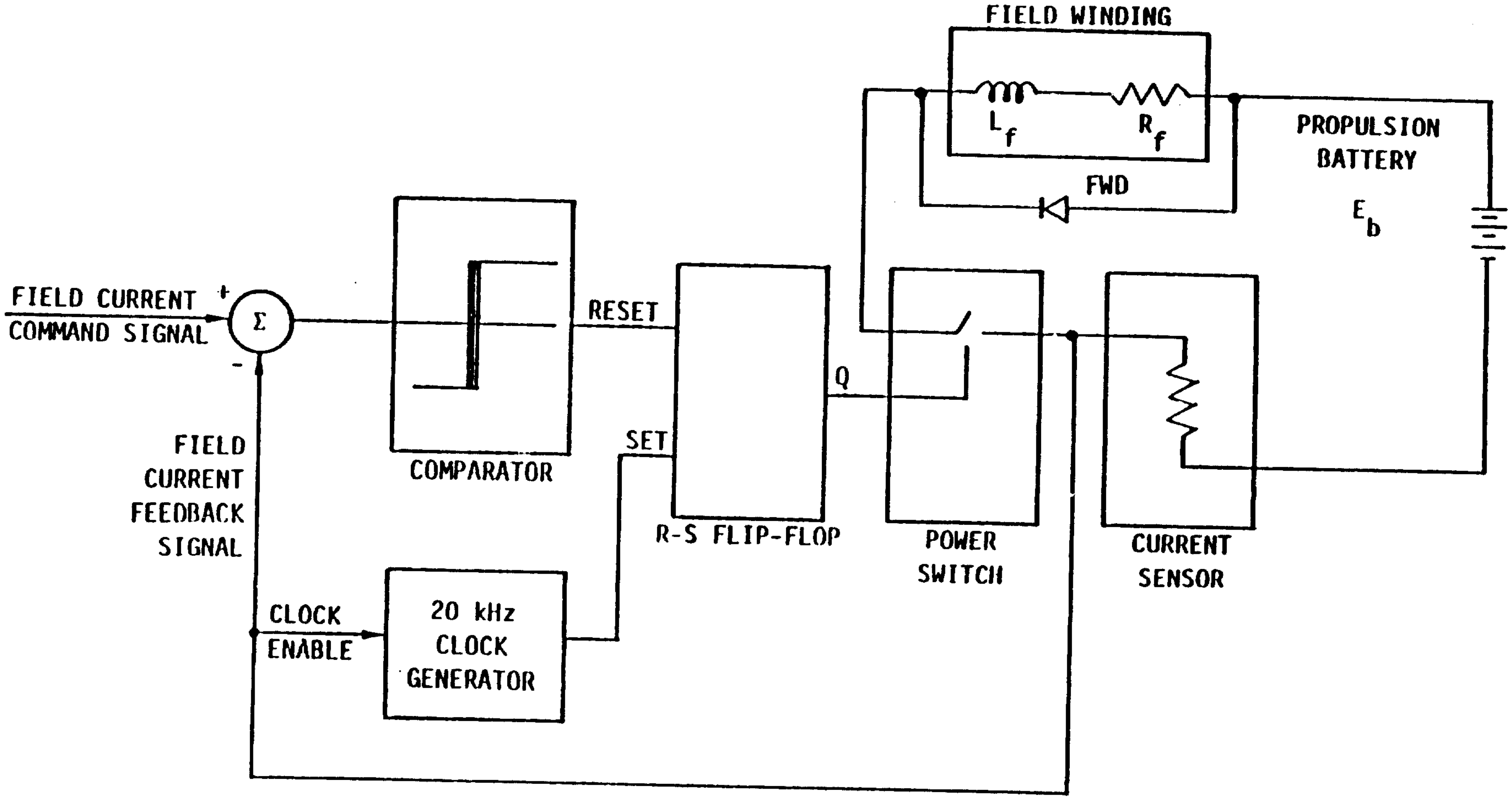


Figure 24. Field Controller

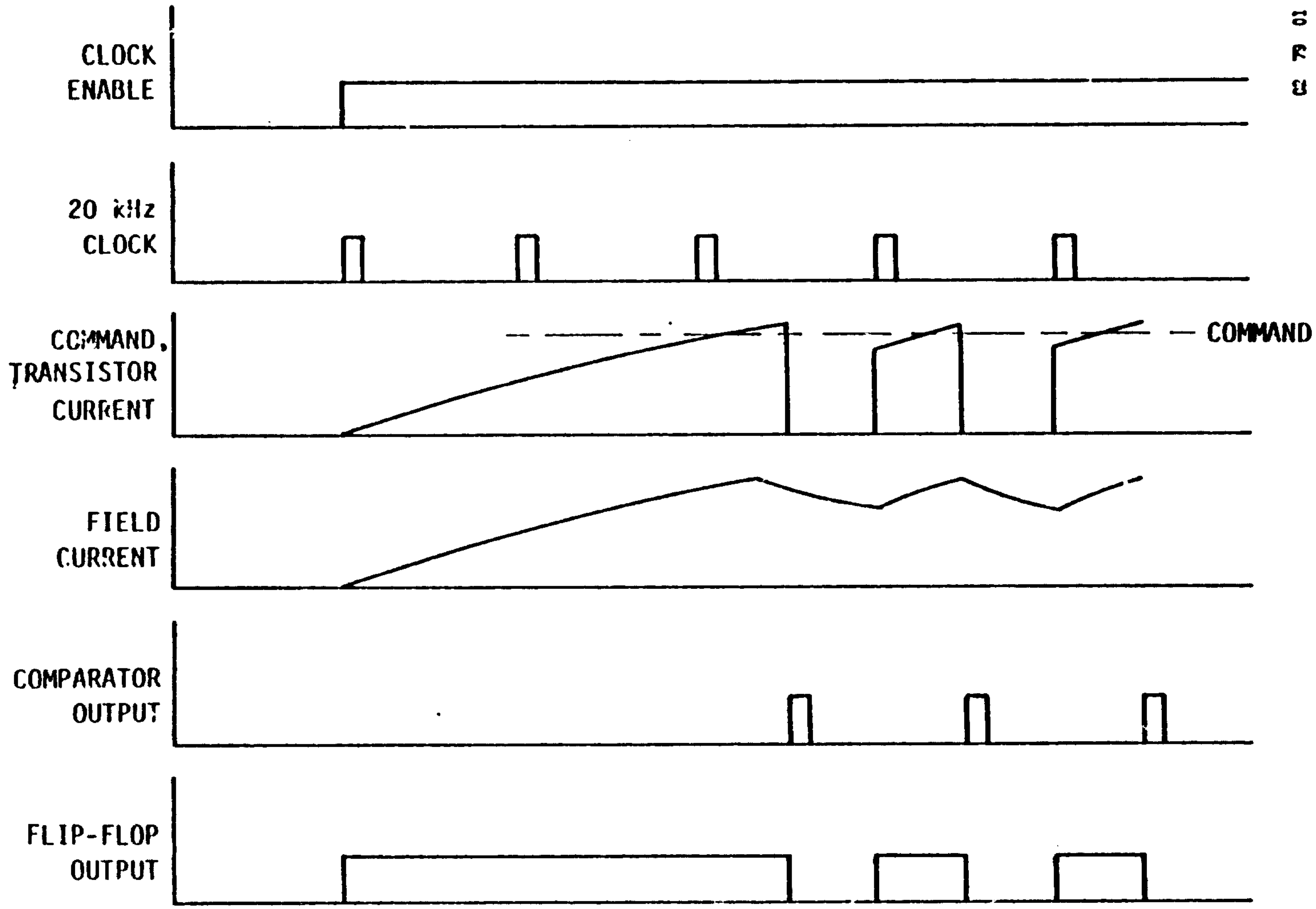
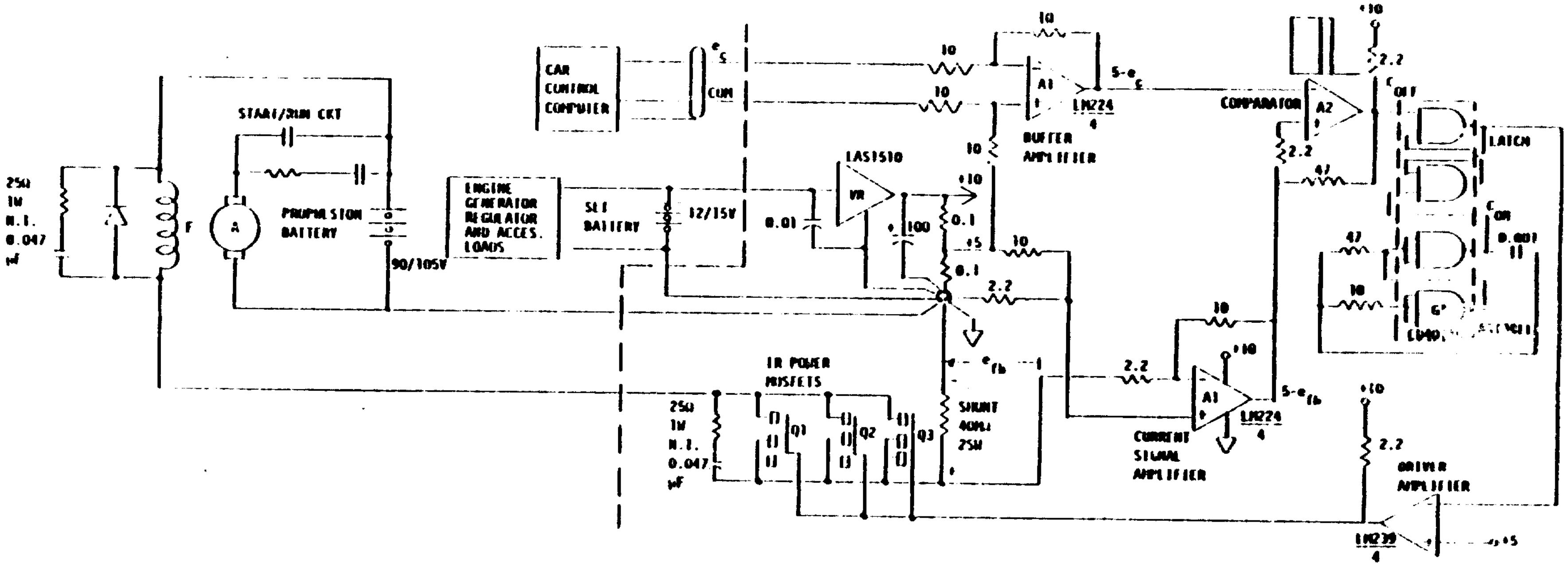


Figure 25. Timing Diagrams



1. VR, Q1, Q2, Q3 are TO-3 packages mounted on heat sink having $R_{\theta} < 0.5°C/W$.
2. All resistors except shunt are 16 pin dip hybrid.
3. A1, A2, G1 are 14 pin dip.

Figure 26. Shunt Field Controller

7.3 BATTERY CHARGER

7.3.1 On-Board Charger

The on-board charger requirements listed in the Vehicle Minimum Requirements of the RFP for this program[24] are

Input: 120 Vac 60 Hz single phase
Output: 15 Adc and 30 Adc maximum.

The primary considerations for the selection of a design approach for the on-board charger are: weight, cost, charger efficiency, input line power factor and electromagnetic radiation. The efficiency of the battery charging process (expressed in terms of energy available from the battery, relative to energy input to the battery during charging) is not a selection factor because any of the charger approaches considered can, through proper design of the low level control circuitry, achieve the acceptable maximum charging efficiency of 70 percent. This circuitry does not significantly impact the overall cost or size of the charger.

There are two feasable approaches to implementing the charger power conversion circuitry: phase controlled 60 Hz SCR rectification of the ac line voltage and high frequency chopper control of the battery current. In either case, transformer isolation is required to avoid the shock hazard. For the 60 Hz approach the weight of the transformer is estimated at 32 kg for the required 4.0 kVA rating. This weight translates to an excessive range penalty, which effectively eliminates controlled 60 Hz rectification from further consideration for the on-board charger.

An on-board charger with acceptable weight can be achieved by changing the 60 Hz line frequency to a frequency of typically 20 kHz. This frequency is high enough to avoid audible sound and low enough to be processed with available power transistors. We estimate the weight of the 4.0 kVA 20 kHz isolation transformer to be 6 kg and we add 5 kg to this for the high frequency output current smoothing inductor. We therefore estimate the total charger weight, including 4 kg of electronic components to be 15 kg.

Figure 27 shows the power electronics components of the charger. The input rectifier, consisting of diodes D1 through D4, converts the 120V-60Hz line voltage into a pulsating dc supply voltage for the push-pull transistor amplifier. The capacitor across the output of the rectifier supplies the 40 kHz ripple current demand

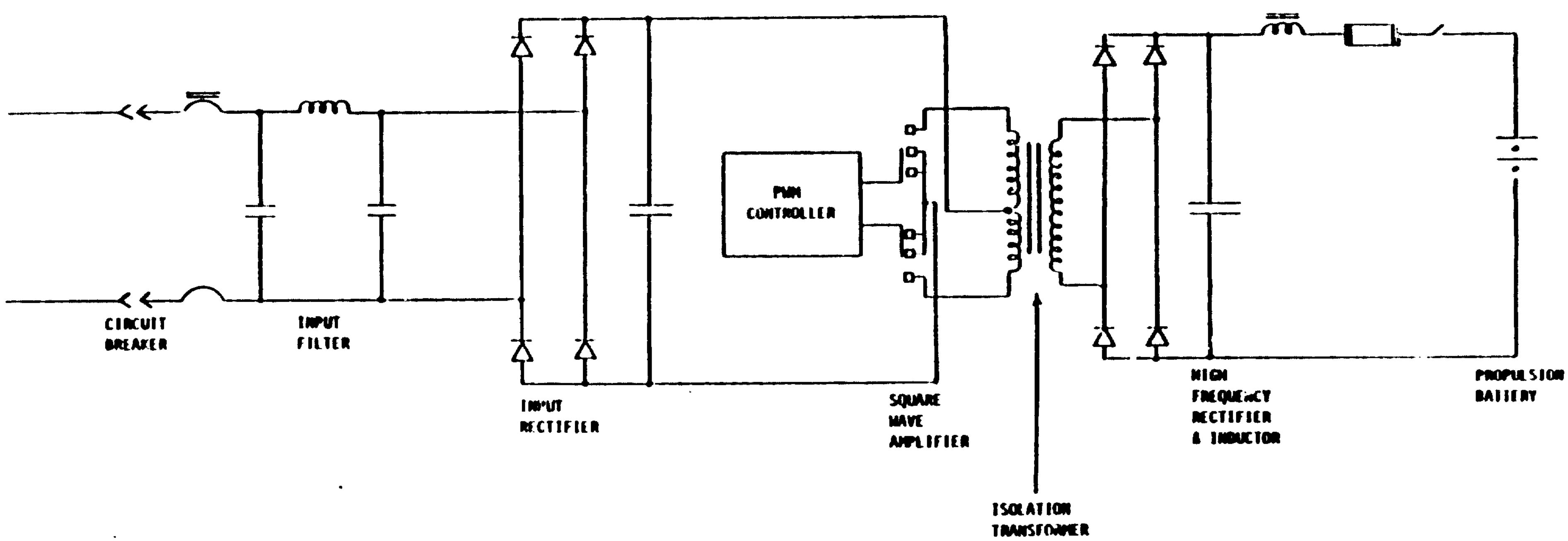


Figure 27. On-Board Charger Power Circuit

of the amplifier to minimize EMI conducted into the 60 Hz mains. EMI is further suppressed by an EMI filter consisting of series inductor and shunt capacitor elements.

The isolation transformer output is rectified by diodes D5 through D8 to form the charger output voltage to the propulsion battery. The high frequency rectifier diodes must be of the fast recovery type to avoid excessive switching losses. These diodes have higher on-state losses than the input rectifier diodes and this affects the size of the rectifier heat sink. The power transistors can be of either bipolar or MOSFET type. Bipolar transistors are available with ratings adequate to avoid the need for parallelling. These transistors are expensive (typically $90.00 each for a Westinghouse D60T in 1000 unit quantities), have considerable switching loss at 20 kHz, and require elaborate base drive circuitry. The much newer MOSFET transistor, however, has minimal switching loss and base drive requirements and is cost competitive with bipolar devices, even when paralleled to obtain a rating equivalent to a single bipolar transistor. Further, the rapid improvements occurring in MOSFET power transistor technology promise to eliminate the need for paralleled transistors in the near future. Therefore we have selected power MOSFET transistors for use in the baseline on-board charger design.

Figure 28 is a series of timing diagrams which indicate how pulse width modulation (PWM) can be used to control the charger output. The time scale is altered to show the effect of increasing battery EMF on the PWM transistor base drive signal.

We should also note that the field supply controller and the on-board charger could be combined. These units are of approximately the same power rating. Their requirements differ chiefly in the need for an isolation transformer in the charger. A weight savings of approximately 10 kg (40 percent), and a similar cost reduction, could be realized by their combination.

7.3.2 Off-Board Battery Charger

The off-board charger requirements listed in the vehicle Minimum Requirements of the RFP for this program[24] are

Input: 208 Vac or 240 Vac, 60 Hz
Output: 60 Adc maximum.

As we mentioned about the on-board charger, the weight, cost, charger efficiency, input line power factor and EMI are design selection factors. The weight of the off-board charger is not critical, but cost, charger efficiency and input line power factor are important factors in determining the practicality of widespread use of both electric and hybrid vehicles.

The phase controlled SCR rectifier provides an efficient and low cost means of ac/dc conversion. Also, the limited range of dc output voltage required for the battery charger application permits a reasonably good input line power factor, in the range of 70 percent to 95 percent. The SCR rectifier approach is penalized by the weight of the required isolation transformer and smoothing inductor. But this weight penalty does not appear to be as severe as the reduced efficiency (primarily due to the need for three power conversion stages) and higher cost at the transistorized off-board charger. Therefore the SCR charger is the preferred approach. Figure. 29 shows the power circuit components of the SCR type off-board charger.

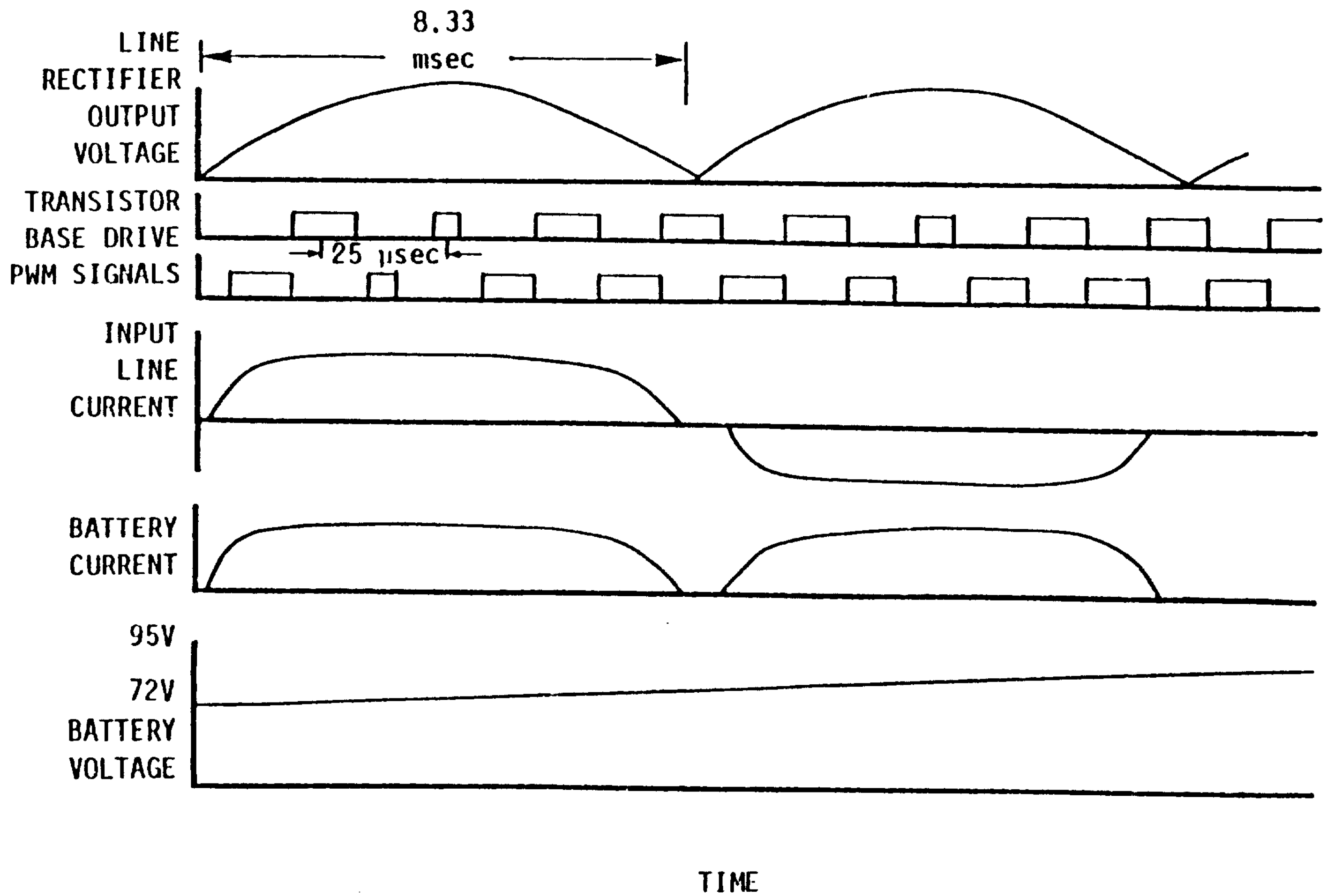


Figure 28. On-Board Charger Waveforms

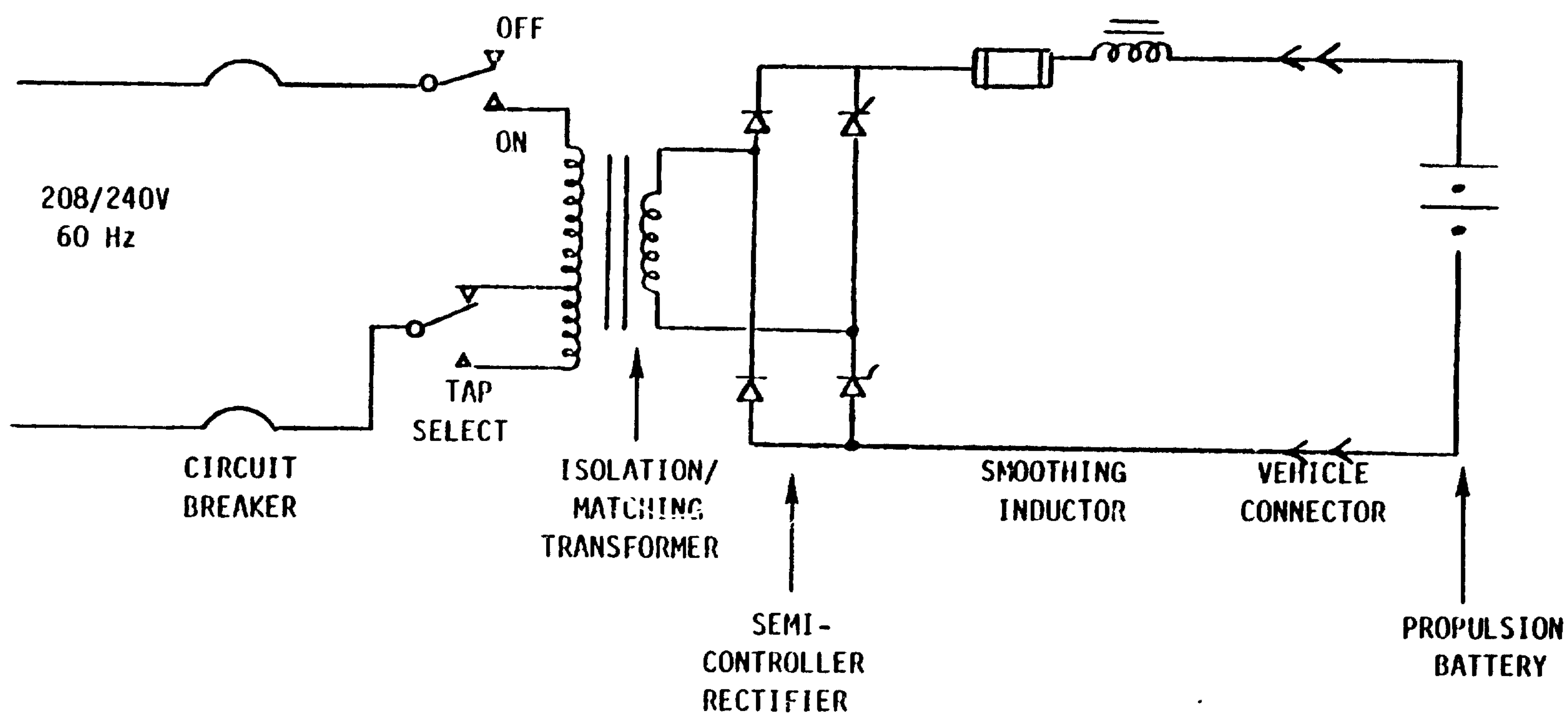


Figure 29. Off-Board Charger Power Circuit

SECTION 8

TRANSMISSION

8.1 TYPE OF TRANSMISSION

In the parallel hybrid vehicle both the heat engine and the electric motor are connected, through separate clutches, to a single transmission. Figure 30 is a schematic layout of the parallel hybrid system. The transmission and clutches are controlled by an on-board microcomputer which both determines the power usage of the heat engine and electric motor and selects the optimum gear ratio for the power plant in use.

Since no continuously variable transmission that is efficient, lightweight and small enough to use in the NTHV will be available in the near term, we investigated the use of a five-speed manual and a three-speed automatic transmission in the baseline NTHV. We inputted the optimum five-speed manual shift schedules (Table 21) into the hybrid vehicle simulation program in order to simulate the heat engine and the electric motor at their most efficient regimes (for the power required). A similar study was conducted for the three-speed automatic transmission. The results of taking the baseline NTHV through the FUDC, FHDC, and SAE J227a(B) cycles are given in Tables 22 and 23.

Table 22. Petroleum and Electricity Consumptions for the Baseline NTHV with Manual and Automatic Transmissions, Electric Motor Primary Drive

Transmission Type	FUDC (ℓ/cycle)	FUDC (Δs/cycle)	FHDC (ℓ/cycle)	FHDC (Δs/cycle)	SAE (ℓ/cycle)	SAE (Δs/cycle)
5-Speed Manual	0.070	0.2624	0.062	0.3711	0.0	0.0057
3-Speed Automatic	0.108	0.3373	0.083	0.3937	0.0	0.0101

Table 23. Petroleum and Electricity Consumptions for the Baseline NTHV with Manual and Automatic Transmissions, Heat Engine Primary Drive

Transmission Type	FUDC (ℓ/cycle)	FUDC (Δs/cycle)	FHDC (ℓ/cycle)	FHDC (Δs/cycle)	SAE (ℓ/cycle)	SAE (Δs/cycle)
5-Speed Manual	0.795	0.0	0.827	0.0	0.024	0.0
3-Speed Automatic	0.929	0.0	0.872	0.0	0.027	0.0

A = Accelerator pedal
B = Batteries
C_E = Engine clutch or torque converter
C_M = Motor clutch or torque converter
D = Differential
E = Internal combustion engine
I = Driver mission data input
K = Strategy and control computer
M = Electric traction motor
S = Direction "gear shift" control
T = Transmission

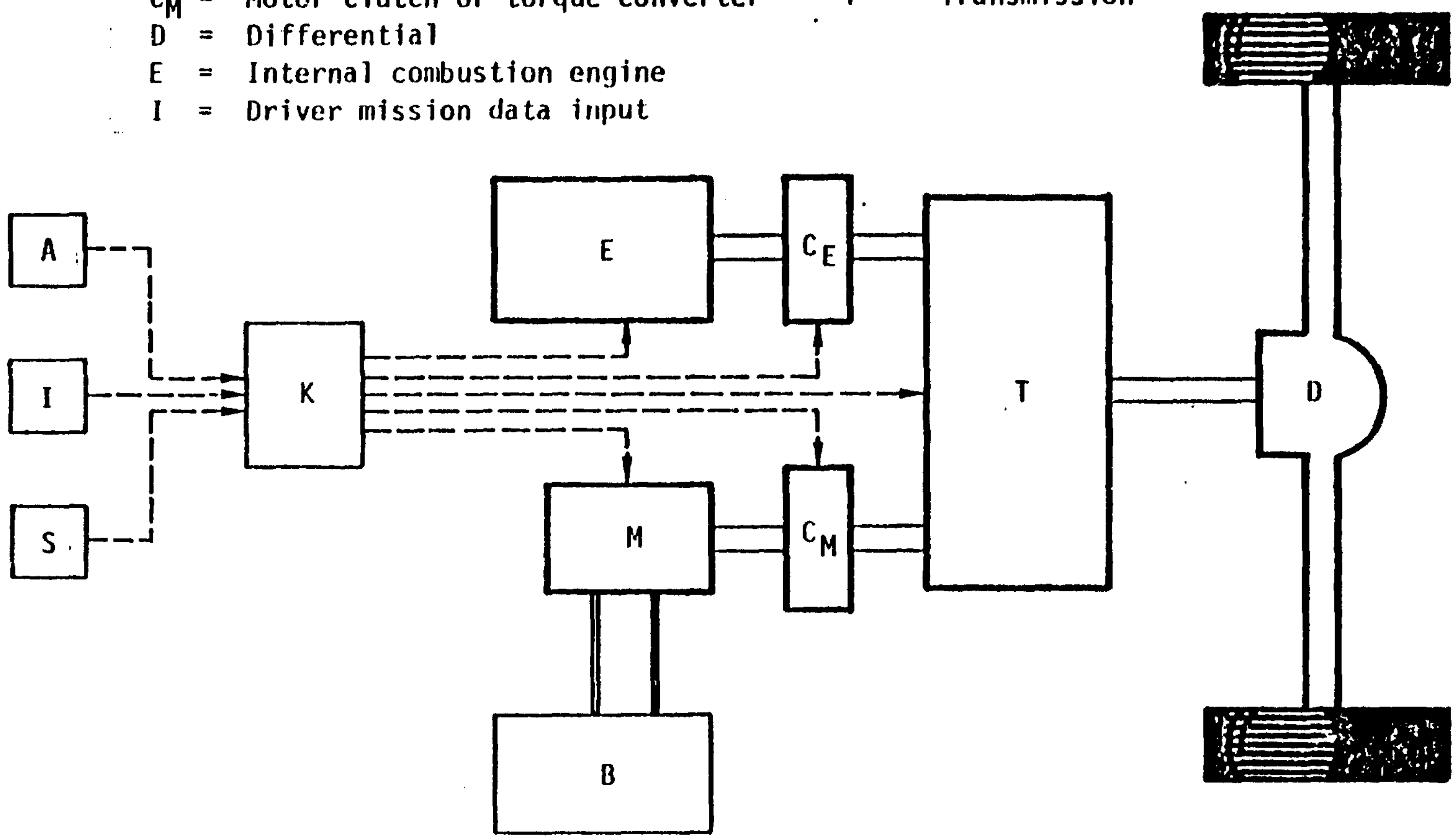


Figure 30. Schematic of NTHV Power Train

Table 21. Five-Speed Manual Transmission Optimimum Shift Schedules

	Shift Curves - Internal Combustion Engine								
First Gear	Upshift RPM	1825	1828	1832	3450	4899	4902		
	Upshift Torque	-999.0	0.0	23.8	39.1	42.3	999.0		
	Downshift RPM	-3450	-3445	-3440					
	Downshift Torque	-999.0	0.0	999.0					
Second Gear	Upshift RPM	1591	1593	1597	2910	3298	4976	4986	4988
	Upshift Torque	-999.0	0.0	25.8	41.2	46.9	49.0	67.0	999.0
	Downshift RPM	1007	1009	1011	1261	1940	2425	2427	
	Downshift Torque	-999.0	0.0	46.4	57.7	77.3	82.5	999.0	
Third Gear	Upshift RPM	1301	1302	1303	1860	3100	3720	4985	4991
	Upshift Torque	-999.0	0.0	24.2	36.3	52.4	58.9	55.6	999.0
	Downshift RPM	1004	1006	1007	1860	2108	2877	2883	2884
	Downshift Torque	-999.0	0.0	44.4	71.0	82.3	84.7	104.8	999.0
Fourth Gear	Upshift RPM	1305	1310	1314	2910	3395	4991	4996	
	Upshift Torque	-999.0	0.0	20.6	49.5	60.8	55.7	999.0	
	Downshift RPM	1008	1009	1010	1455	2425	2910	3511	3516
	Downshift Torque	-999.0	0.0	34.0	51.5	74.2	84.5	79.4	999.0
Fifth Gear	Upshift RPM	4984	4988	4991					
	Upshift Torque	-999.0	0.0	999.0					
	Downshift RPM	1001	1005	1009	2250	2625	3484	3488	
	Downshift Torque	-999.0	0.0	29.3	70.7	86.7	80.0	999.0	

Table 21 (Cont'd)

	Shift Curves - Electric Motor			
First Gear	Upshift RPM	4950	4960	4970
	Upshift Torque	-999.0	0.0	999.0
	Downshift RPM	-5020	-5010	-5000
	Downshift Torque	-999.0	0.0	999.0
Second Gear	Upshift RPM	4950	4960	4970
	Upshift Torque	-999.0	0.0	999.0
	Downshift RPM	1660	1670	1680
	Downshift Torque	-999.0	0.0	999.0
Third Gear	Upshift RPM	4950	4960	4970
	Upshift Torque	-999.0	0.0	999.0
	Downshift RPM	1660	1670	1680
	Downshift Torque	-999.0	0.0	999.0
Fourth Gear	Upshift RPM	4950	4960	4970
	Upshift Torque	-999.0	0.0	999.0
	Downshift RPM	1660	1670	1680
	Downshift Torque	-999.0	0.0	999.0
Fifth Gear	Upshift RPM	4950	4960	4970
	Upshift Torque	-999.0	0.0	999.0
	Downshift RPM	1660	1670	1680
	Downshift Torque	-999.0	0.0	999.0

	Shift Curves - Hybrid Mode			
First Gear	Upshift RPM	4950	4960	4970
	Upshift Torque	-999.0	0.0	999.0
	Downshift RPM	-5020	-5010	-5000
	Downshift Torque	-999.0	0.0	999.0
Second Gear	Upshift RPM	4950	4960	4970
	Upshift Torque	-999.0	0.0	999.0
	Downshift RPM	1660	1670	1680
	Downshift Torque	-999.0	0.0	999.0
Third Gear	Upshift RPM	4950	4960	4970
	Upshift Torque	-999.0	0.0	999.0
	Downshift RPM	1660	1670	1680
	Downshift Torque	-999.0	0.0	999.0
Fourth Gear	Upshift RPM	4950	4960	4970
	Upshift Torque	-999.0	0.0	999.0
	Downshift RPM	1660	1670	1680
	Downshift Torque	-999.0	0.0	999.0
Fifth Gear	Upshift RPM	1660	1670	1680
	Upshift Torque	-999.0	0.0	999.0
	Downshift RPM	1660	1670	1680
	Downshift Torque	-999.0	0.0	999.0

The five-speed manual transmission has 14 percent less fuel consumption in FUDC and 5 percent less fuel consumption in FHDC than the three-speed automatic transmission. When the baseline NTHV was taken through Mission A with the two types of transmission, the results in Table 24 were obtained.

Table 24. Results of Taking the Baseline NTHV Through Mission A with Manual and Automatic Transmissions

Transmission Type	Annual Fuel Consumption (ℓ)	Fuel Economy (km/ℓ)	Annual Electricity Consumption (kW-hr)	Electricity Economy (km/KW-hr)	Electric Range (km)
5-Speed Manual	540	34.42	3225	5.77	36
3-Speed Automatic	667	27.89	3667	5.07	30

The cost and weight panalties of the automatic transmission add to the fuel consumption penalty and show significantly in the life cycle costs given in Table 25.

Table 25. Economic Analysis of the Baseline NTHV with Manual and Automatic Transmissions

Transmission Type	Benefit (1978 $)	Cost of Accruing this Benefit (1978 $)	Life Cycle Cost (1978 $)	Breakeven Petroleum Price	
				($/ℓ)	($/gal)
5-Speed Manual	3101	7668	24495	0.62	2.35
3-Speed Automatic	2802	8047	25173	0.72	2.73

For both petroleum savings and life cycle costs, the five-speed manual transmission is the best choice for the near term hybrid. But it would have marketability problems. These problems could be greatly reduced by microcomputer control of the manual transmission and the two clutches. Such automatic control would also aid the efficiency of the powertrain. Based on the control strategy chosen, it would determine the choice of engine or motor, the power setting and the optimum gear ratio.

However, this system has one shortcoming — it still depends on a manual transmission, and, therefore, it can not be shifted under power. The engine/motor power must be disconnected by disengaging a clutch before the transmission can be shifted, and will remain disconnected for a minimum of 0.5 seconds during the shift. The power can only be reconnected to the driving wheels after the shift is completed. While this loss does not cause a problem on driver controlled manual transmissions (because the driver controls the time of shifting), it may be unacceptable to the driver of the computer controlled manual transmission. An automatic transmission, because of its planetary geartrain, can be shifted under load, so there is no unexpected loss of acceleration or gradeability when the shifting control decides that the optimum time for shifting has arrived.

As a result of this possible shortcomming, we are considering the use of a computer controlled automatic transmission, with computer control of both the transmission shifting and the torque converter lock-up clutch. Although the automatic transmission losses can never be reduced to the level of a manual transmission, the power losses of the automatic shown above could be significantly lowered by careful design.

8.2 GEAR RATIOS

For the five-speed computer controlled manual transmission, we investigated the two different sets of gear ratios listed in Table 26. The comparative results are given in Tables 27 through 30. These tables show that a 10 percent variation in the low gear ratios does not affect the baseline NTHV performance, fuel economy, or life cycle costs.

Table 26. 5-Speed Manual Transmission Gear Ratios

Gear Number	Baseline Gear Ratios	Trial Gear Ratios
1	3.45	3.80
2	1.94	2.14
3	1.24	1.37
4	0.97	1.07
5	0.75	0.75

Table 27. Petroleum and Electricity Consumptions for the Baseline NTHV with Different Gear Ratios, Electric Motor Primary Drive

Range of Gear Ratios	FUDC (ℓ/cycle)	FUDC (ΔS/cycle)	FHDC (ℓ/cycle)	FHDC (ΔS/cycle)	SAE (ℓ/cycle)	SAE (ΔS/cycle)
3.45 → 0 .75	0.070	0.2624	0.062	0.3711	0.0	0.0057
3.80 → 0 .75	0.083	0.2587	0.062	0.3677	0.0	0.0057

Table 28. Petroleum and Electricity Consumptions for the Baseline NTHV with Different Gear Ratios, Heat Engine Primary Drive

Range of Gear Ratios	FUDC (ℓ/cycle)	FUDC (ΔS/cycle)	FHDC (ℓ/cycle)	FHDC (ΔS/cycle)	SAE (ℓ/cycle)	SAE (ΔS/cycle)
3.45 → 0 .75	0.795	0.0	0.827	0.0	0.024	0.0
3.80 → 0 .75	0.790	0.0	0.846	0.0	0.023	0.0

Table 29. Results of taking the Baseline NTHV Through Mission A with with Different Gear Ratios

Range of Gear Ratios	Annual Fuel Consumption (ℓ)	Fuel Economy (km/ℓ)	Annual Electricity Consumption (kW-hr)	Electricity Economy (km/KW-hr)	Electric Range (km)
3.45 → 0.75	540	34.42	3225	5.77	36
3.80 → 0.75	549	33.87	3218	5.78	36

Table 30. Results of the Economic Analysis of the Baseline NTHV with Different Gear Ratios

Range of Gear Ratios	Benefit (1978 \$)	Cost of Accruing this Benefit (1978 \$)	Life Cycle Cost (1978 \$)	Breakeven Petroleum Price [\$/ℓ	(\$/gal)]
3.45 → 0.75	3101	7668	24495	0.622	(2.35)
3.80 → 0.75	3080	7666	24513	0.624	(2.36)

8.3 FINAL DRIVE

A similar analysis of the final drive ratios has shown that the hybrid performance characteristics, fuel economy, and life cycle costs are insensitive to small variations (on the order of 10 percent) in the final drive ratio. The baseline NTHV final drive ratio is 3.90.

8.4 REGENERATIVE BRAKING

Another method by which the fuel economy of the hybrid vehicles can be improved is through the recovery and re-use of braking energy. The extensive studies described in References 25 and 26 show the feasibility of regenerative braking systems in vehicles. The baseline NTHV was taken through different driving cycles with and without regenerative braking. The results are given in Tables 31 and 32. The baseline NTHV with regenerative braking has a 16 percent electricity consumption saving in FUDC and a 4 percent electricity consumption saving in FHDC.

Table 31. Petroleum and Electricity Consumptions for the Baseline NTHV With and Without Regenerative Braking, Electric Primary Drive

Regenerative Braking	FUDC (ℓ/cycle)	FUDC (ΔS/cycle)	FHDC (ℓ/cycle)	FHDC (ΔS/cycle)	SAE (ℓ/cycle)	SAE (ΔS/cycle)
Yes	0.070	0.2624	0.062	0.3711	0.0	0.0057
No	0.063	0.3133	0.056	0.3867	0.0	0.0065

Table 32. Petroleum and Electricity Consumptions for the Baseline NTHV With and Without Regenerative Braking, Heat Engine Primary Drive

Regenerative Braking	FUDC (ℓ/cycle)	FUDC (ΔS/cycle)	FHDC (ℓ/cycle)	FHDC (ΔS/cycle)	SAE (ℓ/cycle)	SAE (ΔS/cycle)
Yes	0.795	0.0	0.827	0.0	0.024	0.0
No	0.774	0.0029	0.817	0.0026	0.023	0.0

We then combined the driving cycles to represent Mission A and obtained the results in Table 33. In this mission the recovery and re-use of braking energy would save 5.6 percent of the petroleum and 4.7 percent of the electric energy per year. We estimate the manufacturing cost of a regenerative braking system for a hybrid vehicle to be approximately $15 (in 1978 dollars). The results of the life cycle cost analysis with and without regenerative braking are given in Table 34. The benefit gained by regenerative braking is cost effective in the hybrid vehicles. The same result was also found in Reference 25.

Table 33. Results of Taking the Baseline NTHV Through Mission A with and Without Regenerative Braking

Regenerative Braking	Annual Fuel Consumption (ℓ)	Fuel Economy (km/ℓ)	Annual Electricity Consumption (kW-hr)	Electricity Economy (km/KW-hr)	Electric Range (km)
Yes	540	34.42	3225	5.77	36
No	572	32.50	3381	5.50	31

Table 34. Results of the Economic Analysis of the Baseline NTHV With and Without Regenerative Braking

Regenerative Braking	Benefit (1978 $)	Cost of Accruing This Benefit (1978 $)	Life Cycle Cost (1978 $)	Breakeven Petroleum Price [$/ℓ	($/gal)]
Yes	3101	7668	24495	0.62	(2.35)
No	3025	7644	24546	0.64	(2.40)

SECTION 9

ACCESSORIES

The heat engine and vehicle accessories (such as the cooling fan, water pump, alternator, air pump, and air conditioner) use as much as 40 percent of the total power required. A typical accessory power requirement is given in Figure 31. It has been shown[27] that a constant, low speed accessory drive can improve fuel economy approximately 10 percent. When the accessory power requirements are added to the road power requirements in a hybrid vehicle, the fuel economy drops dramatically, as shown in Table 35.

Table 35. Effects of Accessories on the NTHV

System Description	Annual Fuel Consumption (ℓ)	Fuel Economy (km/ℓ)	Electric Range (km)
Baseline NHTV, no accessories	540	34.4	34
Baseline NTHV, accessories, no air conditioning	752	24.7	24
Baseline NTHV, accessories and air conditioning	940	19.8	19

The results in Table 35 were obtained by taking the baseline NTHV through Mission A. The total power (road plus accessory power) comes from both the heat engine and the electric motor, according to an assigned control strategy. This strategy is to first use the electric motor topped by the heat engine until the batteries reach their allowable depth of discharge and, thereafter, to use the heat engine topped by the electric motor. The addition of accessory power significantly decreases the hybrid vehicle fuel economy and electric range.

Another strategy is to take the accessory power only from the heat engine and the road power from both power plants. Unfortunately, this strategy further reduces the fuel economy for the baseline

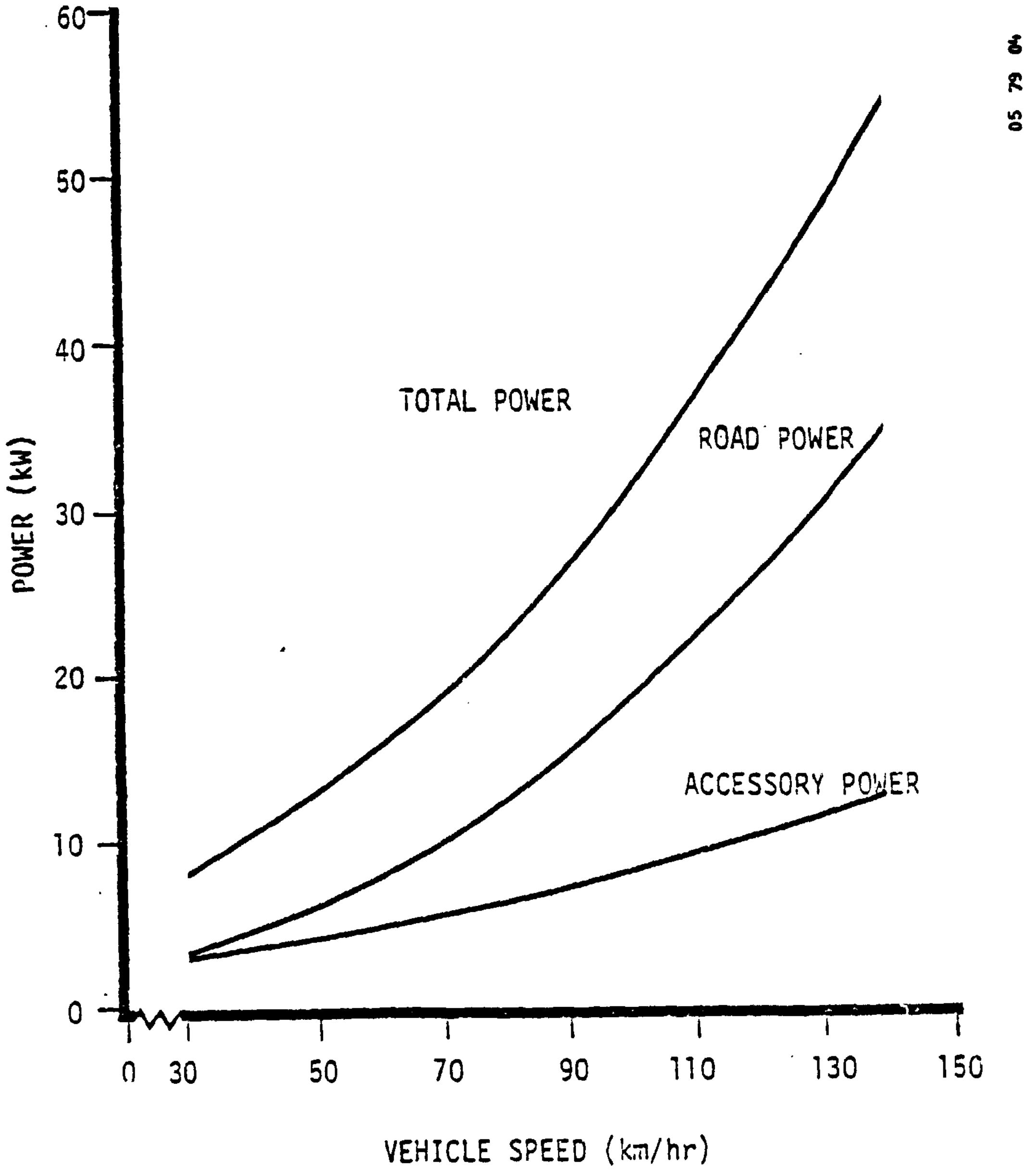


Figure 31. Accessory Power Requirements in an Intermediate Class ICE Vehicle

NTHV, to 16.0 km/ℓ. An example of the typical petroleum consumption behavior under this strategy is given in Figure 32. This figure shows that for daily travel distances less than 37 km in FHDC, the accessory power should come from both power sources, and, for daily travel distances greater than 37 km in FHDC, the accessory power should come only from the heat engine. For a 50 km daily travel distance in FHDC, this strategy betters the petroleum savings by 8.3 percent.

Several NTHV system packages were studied in order to find the battery, heat engine and electric motor combination that will provide all the road load and the auxiliary requirements (including the air conditioner), while bettering the required fuel economy and keeping the life cycle cost as low as possible. With a 48.5 kW heat engine, 29 kW electric motor and 84V battery, the baseline NTHV yielded 21.9 km/ℓ (51.7 mpg) with the accessories and the air conditioner on. It reached 26.5 km/ℓ (62.6 mpg) with the accessories on, but without the air conditioner. The accessories were driven by a constant, low speed drive and the power to the drive was provided by both power sources.

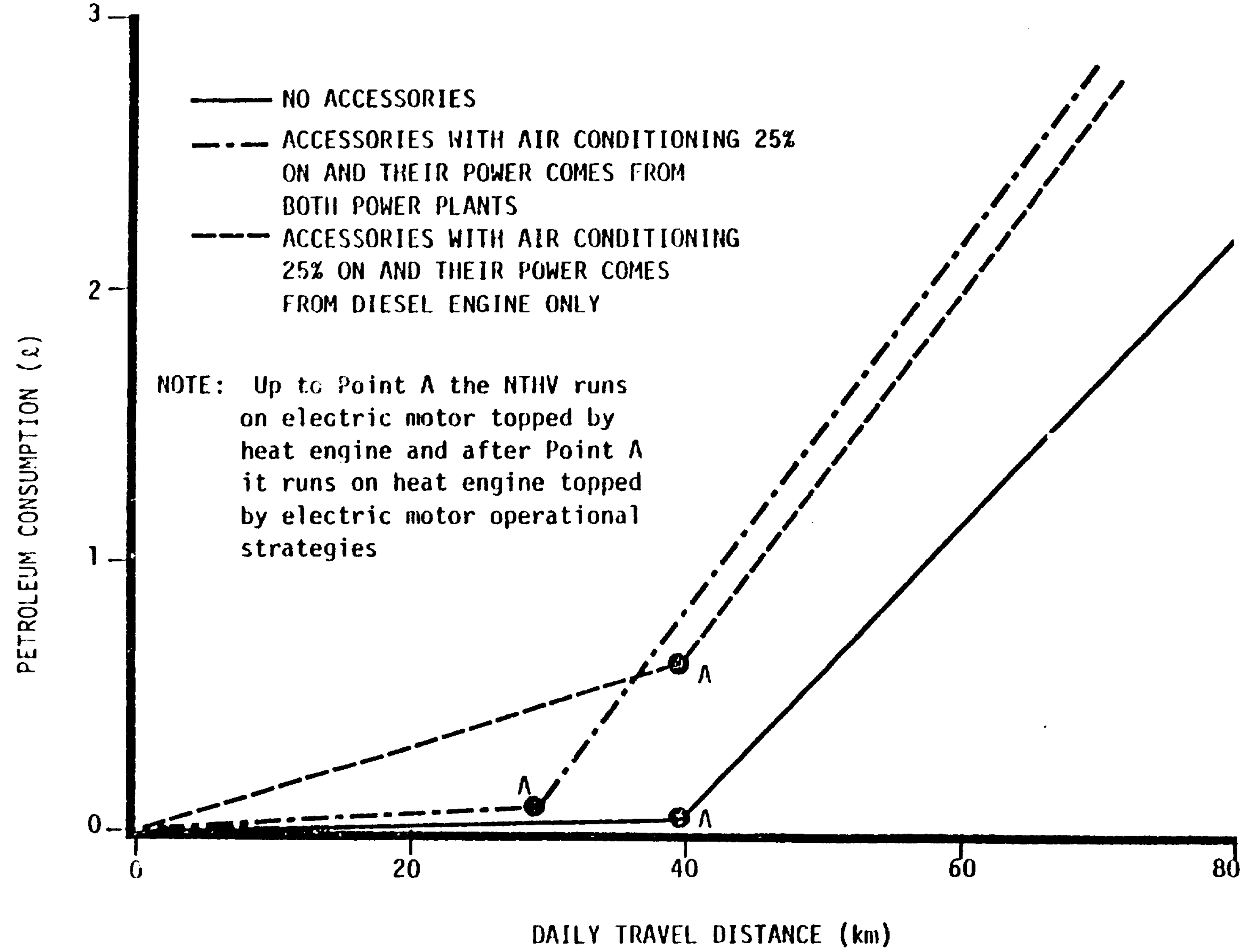


Figure 32. Petroleum Consumption Versus Trip Length in FHDC for Various Operational Strategies, with and without Accessories

SECTION 10

TEMPERATURE CONTROL AND COLD STARTS

10.1 HEATING AND COOLING REQUIREMENTS

In cold climates the heating and defrosting requirements for both passenger comfort and battery temperature control can be as high as 3421 kcal/hr. When the heat engine is the primary drive component, the heat required can be drawn from the engine cooling water by a heat exchanger. For the engine sizes under consideration in this study, the heat release to cooling water would be sufficient at about 1000 rpm. But, when the electric motor is the primary drive component, to use the heat engine for heating, defrosting and battery temperature control would require three times as much petroleum as a separate petroleum-burning heater. A separate heater would have a unit manufacturing cost of approximately $300 (1978$) for 100,000 units per year. This cost would be returned in full during the ten year lifetime of the hybrid and, at the same time, save 1880 liters of petroleum.

The cooling requirements for passenger comfort may be as high as 1666 kcal/hr. The requirements for the batteries are much lower. The heat gained from the electrochemical reaction in the batteries is approximately 3.385 I Watts[10] for the 84V battery package. While using the electric motor as the primary drive component, the battery package temperature can rise 9°C above ambient in one hour, if no ventilation is provided. This order of temperature rise should not cause any problem in battery performance. The temperature of the battery package will be controlled by the microprocessor and the cooling power will come from both power sources, as discussed in Section 9.

10.2 COLD STARTS

Cold start in hybrid vehicles causes a high loss of stored electricity. A battery pack starting at 0°C ambient temperature without warmup could spend half its battery capacity[10,28] (Figure 33). This would decrease the electric range of the baseline NTHV from 36 to 15 km. Further, an unprotected lead-acid battery would not operate a vehicle after a week of cold soak at -29°C[10]. Therefore, the hybrid vehicle should have a self-contained warm-up system. This system should be strong enough that the vehicle could reach

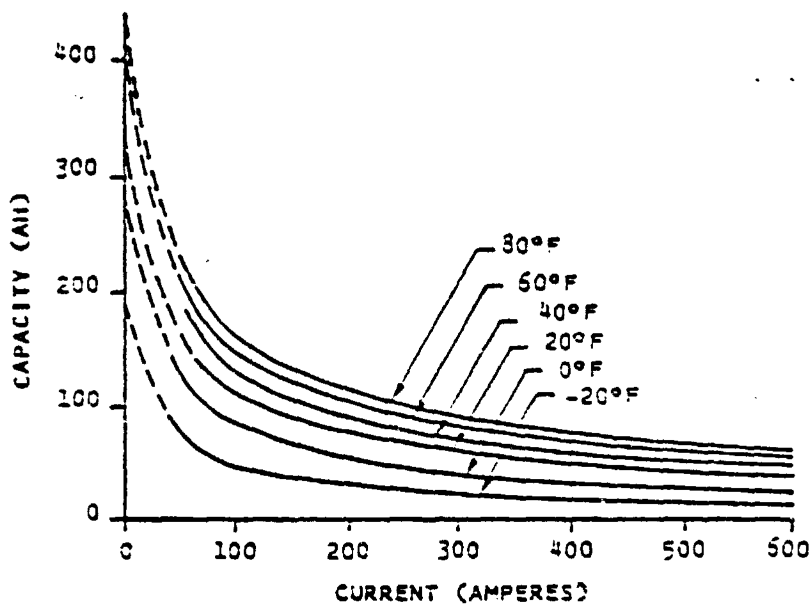


Figure 33. Effect of Temperature on Battery Capacity in a 6-volt Lead-acid Battery

full performance levels in a maximum of ten minutes in ambient temperatures greater than -20°C. Also, the vehicle must be operable within one minute in the ambient temperature range from -20 to +40°C.

There are four alternatives for heating the battery package before usage.

1. Warm the heat engine and also the battery package (self-contained warm-up)

2. Warm the battery package with its own stored energy (self-contained warm-up)

3. Warm the battery package with a separate petroleum-burning heater (self-contained warm-up)

4. Warm the battery package and the heat engine with wall plug electricity energy during charging (external warm-up).

In our comparison of these methods the battery package was assumed to be a rectangular box insulated with a fiberglass-polyurethane-fiberglass sandwich structure which has an effective thermal conductivity of 0.043 kcal/hr-m-°C.

The first method would meet all the minimum cold start requirements at the expense of high fuel consumption and high thermal stresses (that would deteriorate the heat engine life).

The warm-up of the battery package with its own stored energy would require 80.5I watts[10] for an 84V battery package. A ten minute warm-up period would require 242 amps discharge current and reduce the electric range of an 84V battery pack NTHV from 49 to 31 km.

The warm-up of the battery package with a separate petroleum-burning heater would take about twenty minutes and would consume half the fuel used in the first method.

The warm-up of the battery package with the heat engine with wall plug electricity would be the best solution for both time and petroleum consumption. If this external warm-up power is not available, and self-contained warm-up has to be utilized, the battery package and the heat engine would be warmed by the petroleum-burning heater, up to the maximum allowable time limit. Then the initial operational strategy would be to use the heat engine as the primary drive component, since the average ratio of cold-start highway fuel economy to standard highway fuel economy is only 0.914[1]. After the battery package reaches 27°C, the electric motor would be used as the primary drive component.

SECTION 11

OPERATIONAL STRATEGIES

11.1 INTRODUCTION

A driver requests power of a vehicle by depressing the accelerator pedal and activating such accessories as the radio and air-conditioner. The hybrid can respond through its electric motor, heat engine, or both. This section discusses some results of our research into strategies to control the hybrid's response. The ultimate objective is, of course, to develop a strategy which minimizes the hybrid's petroleum consumption nationwide.

The Mission Analysis and most of the Trade-Off Studies assume a simple "initial" strategy in which the electric motor is operated up to its performance limits from the start of each day (electric motor primary drive). The heat engine is used only for topping (providing the difference between a peak power demand and the motor's maximum capability) until the state of discharge reaches 80 percent, at which time the engine becomes the principal supplier of power (engine primary drive). In this section we examine ways upon which the initial strategy can be improved.

Our research indicates the following conclusions.

- Electric motor primary drive is suited better to urban than to highway driving. Thus, if a hybrid's daily activities include relatively long segments of both highway and city driving, less petroleum would be expended under a strategy which uses the motor as the primary power source during the urban segment. Choosing the correct driving environment for the electric mode can improve fuel economy by over 20 percent.

- When a hybrid is driven in the city beyond a certain distance (approximately 37 km for the hybrids examined here) there is some merit in restricting the motor's power output to levels below its actual capability. Conditions exist under which such a limiting strategy can cut petroleum consumption by 19 percent.

- Restricting the motor's power output is never appropriate in highway driving.

- Use of the air-conditioner indicates two possible actions:

  1. Switch from the electric to the heat engine primary drive, if the hybrid will later be operated with the air-conditioner off. Such subsequent travel would have to be of sufficient length to discharge the remaining battery.

  2. Run the air-conditioner off the motor, using the diesel for topping.

  The accessories should never be run by the diesel while the motor is the principal source of power for propulsion.

- The "initial" strategy is a good performer, primarily because

  1. It consumes the minimum amount of fuel on days that the initial strategy's electric range is not exceeded

  2. In Mission A most vehicles do not exceed this electric range.

  Thus, while some additional petroleum savings may accrue by switching from the initial to a more sophisticated strategy, we estimate that this benefit would not exceed 5 percent.

We have concentrated our effort on two hybrid packages which the Trade-off Studies indicate are strong candidates: A) 29 kW motor, 46.2 kW diesel and 84 Volt battery; and B) 24 kW motor, 48.5 kW diesel and 72 Volt battery. For brevity, these packages will be referred to as Hybrids A and B, respectively.

Great care must be used in extrapolating results to other hybrids. The actual benefits of a control strategy depend largely on the specific hybrid configuration. We anticipate, however, that our final design will not deviate grossly from those examined here. Thus, our conclusions should provide a good idea of the eventual results.

Three kinds of strategies will be discussed: initial, omniscient, and on-board. The omniscient strategy is based on a priori knowledge of the hybrid's daily activities and thus avoids mistakes which the initial strategy would make. Such a strategy's responses represent our best current approach to reducing fuel consumption. The actual algorithm carried by the hybrid's microprocessor is the on-board strategy, the design of which is the final objective of this research.

We will first examine several ways in which prior knowledge can lead to reducing petroleum consumption. Extreme cases are presented in which the omniscient strategy substantially outperforms the initial. The factors underlying such extreme cases are then described in Sections 11.3 and 11.4, which outline the effects of limiting motor power and of running accessories. Section 11.5 discusses the relative merits of using the motor in a variety of ways. Finally, Section 11.6 contains an estimate of the maximum potential petroleum savings resulting from switching from the initial to a more sophisticated control strategy on Mission A.

11.2 SOME EXTREME SCENARIOS

Circumstances exist in which an omniscient strategy (and thus, perhaps, a sophisticated on-board strategy) would substantially reduce daily petroleum consumption. As a simple example, the driving cycle 3 of Figure 34 consists of a 50 km leg at 88 km/hr and a 133 km leg at 22 km/hr. For Hybrid B the initial strategy would discharge the battery completely over the 88 km/hr first leg, necessitating a 10.7 liter petroleum outlay to complete the cycle. The omniscient strategy would operate the heat engine over the 88 km/hr leg and the motor over the 22 km/hr second leg, thus draining the battery and consuming a total of just 2.3 liters of petroleum. The reduction in fuel consumption would be a substantial 79 percent.

This unlikely example has a more reasonable analog. Suppose that 40.8 km of the FHDC were followed by 39.8 km of the FUDC. For Hybrid A the initial strategy would discharge the battery 80 percent over the highway travel and burn a total of 2.78 liters of fuel during the outlined course. Once again, the omniscient strategy would use the diesel for the high-speed leg and the motor for the urban portion. The result would be a final battery discharge of 80 percent and a total petroleum consumption of just 2.17 liters. The decrease in petroleum consumption would be 0.61 liter, or 22 percent.

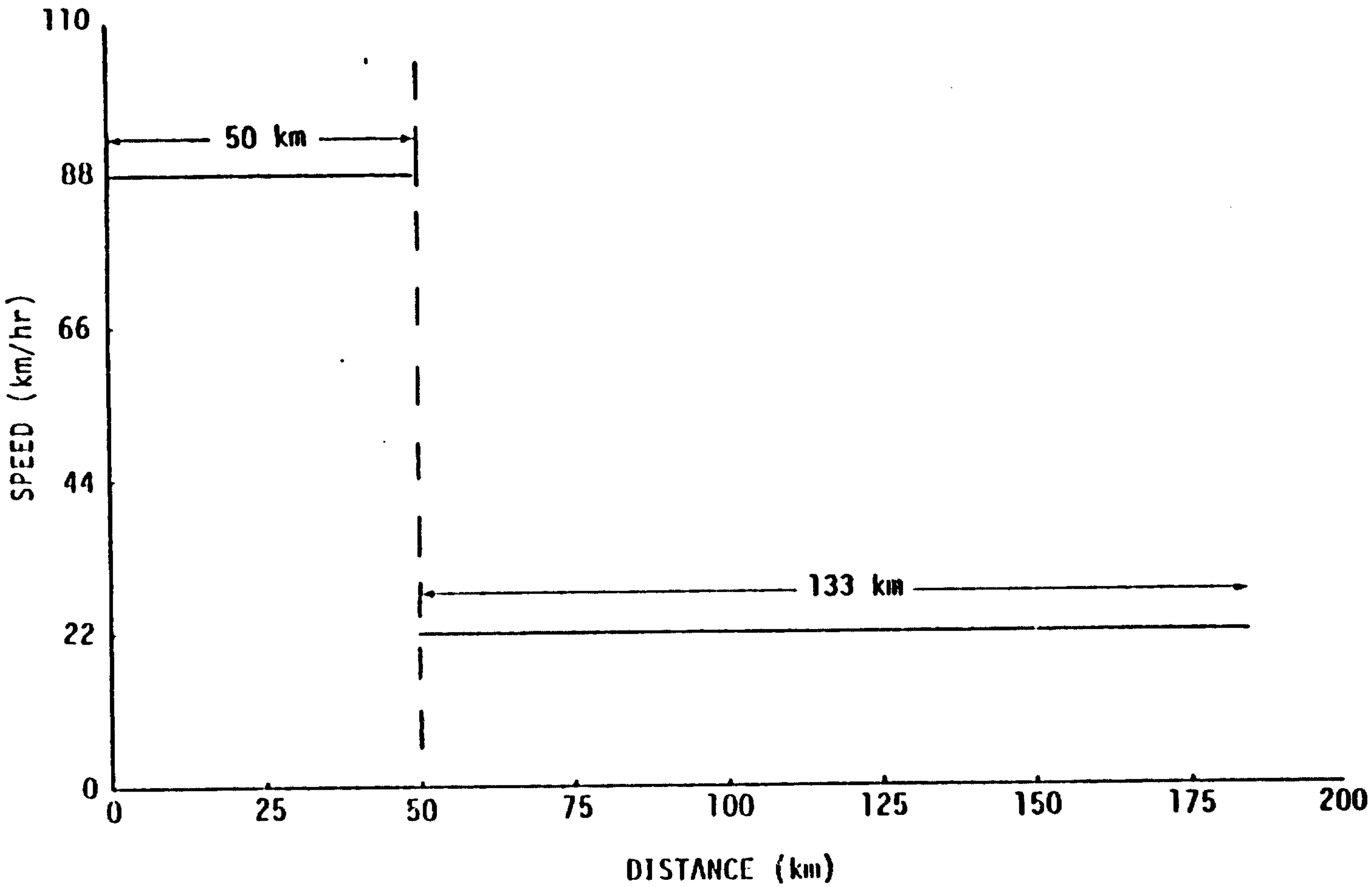


Figure 34. A Simple Driving Cycle

A third example: a 40.8 km highway leg is followed by 53 km of urban driving. The initial strategy would consume a total of 3.69 liters of petroleum. Over such a course, the omniscient strategy would not only wait for the urban leg before using the motor as the primary power source, it would also limit the 29 kW motor to a maximum power output of just 15 kW. A power demand above 15 kW would be met by using the engine for topping. Such a strategy would result in just 2.9 liters of petroleum being consumed, a result which betters that of the initial strategy by 0.79 liter, or 21 percent.

A total of 3.07 liters would have been consumed if the motor had been allowed to produce up to 29 kW during the FUDC portion of this driving course. The petroleum savings resulting from limiting the motor's output to 15 rather than 29 kilowatts therefore is 0.17 liter or 5.6 percent. Had the course consisted only of the second leg — 53 km of the urban cycle — the strategy of a 15 kW limit would have paid a higher percentage dividend. Total petroleum consumption using a 29 kW strategy over the shortened course would have been 0.91 liter, so that a reduction of 0.17 liter would have meant nearly 19 percent less fuel consumption.

11.3 STRATEGIES WHICH LIMIT THE MOTOR'S POWER OUTPUT

The motor draws battery charge at a rate determined by its power requirement and the state of discharge. The rate of draw, in turn, has a substantial effect on the total available battery energy, as has been indicated above by Figure 13. The slower the rate of discharge, the greater is the total available battery energy.

We examine here the effect on fuel consumption of restricting the motor's power output to levels less than its maximum capability. The rationale is this: the hybrid requires a certain total energy, E_T, to travel a distance d. Part of E_T is supplied by the batteries through the motor (E_B), and part by petroleum through the heat engine (E_P). That is,

$$E_T = E_B + E_P \quad .$$

At distances beyond the initial strategy's electric range, an increase in E_B should decrease E_P, thus reducing petroleum consumption. In theory, limiting maximum motor power should increase E_B.

Figure 35 shows the effect, over the FUDC, of limiting Hybrid B's motor to maximum power levels ranging from 15 to 29 kilowatts.

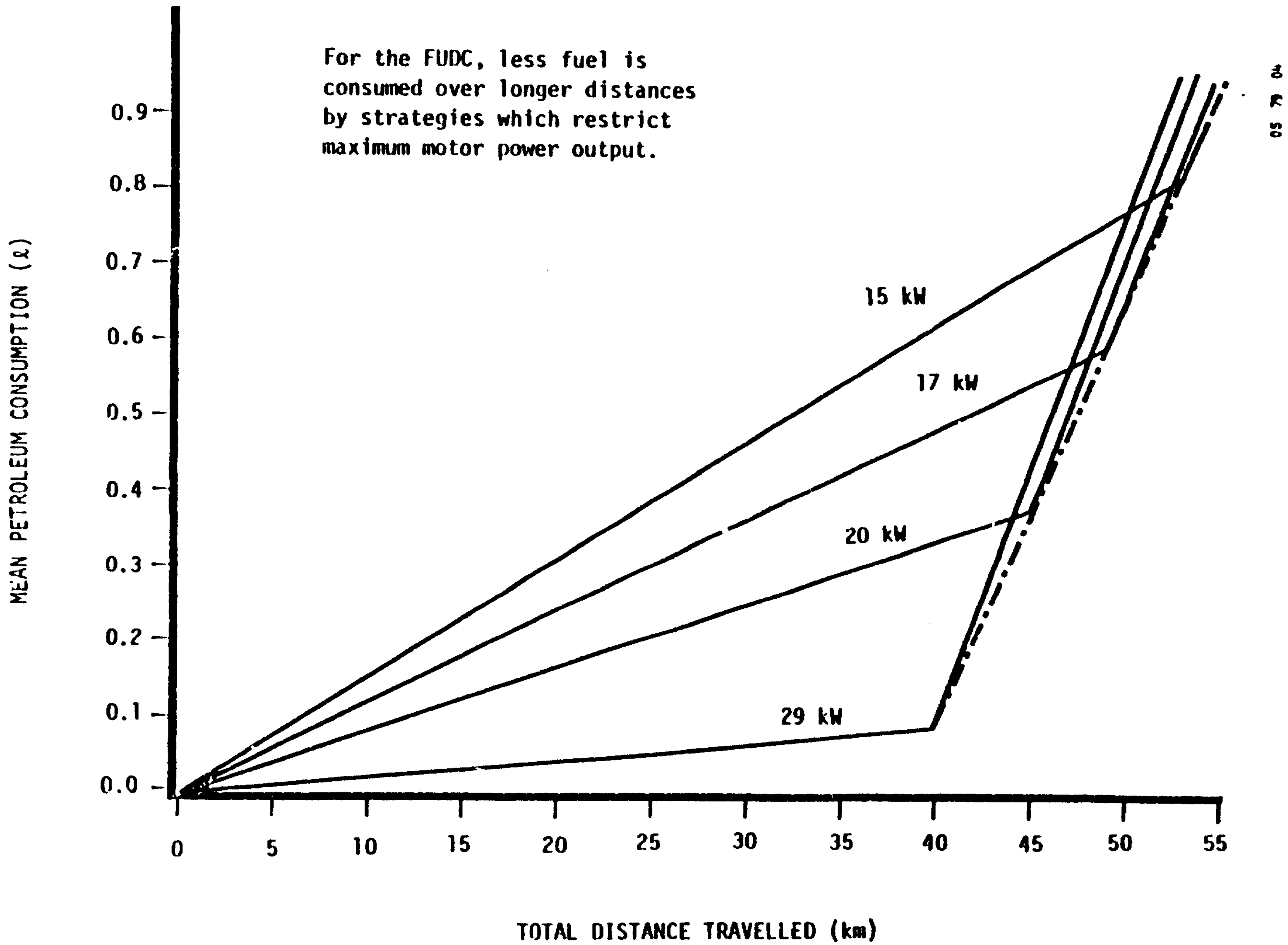


Figure 35. Results of Power Limiting Strategies for Hybrid B Over the FUDC

The diesel here is used for topping. As expected, strategies which limit motor power save more fuel at the longer distances. An unexpected result is that this trend does not continue below 15 kilowatts. Thus, the best strategy for Hybrid A traveling any distance beyond 50 km is to limit the motor to 15 kW. The difference in fuel consumption between the initial and 15 kW strategies is 0.17 liter, which is 19 percent of the total consumption at 53 kW.

Surprisingly, strategies which limit the motor's power do not improve fuel economy on long trips for Hybrid A operating over the FHDC. Instead, our computer simulations indicate that the initial strategy consumes a minimum of petroleum regardless of the distance traveled.

11.4 RUNNING ACCESSORIES

We have examined, in Section 9, the effect on fuel consumption of running accessories. Of particular interest is whether the air-conditioner and other accessories would overburden the motor, which might indicate running the accessories off the engine at all times.

Our results indicate the following.

- Not surprisingly, use of accessories substantially increases battery and petroleum consumption rates. When the diesel is the primary power source, a 3.75 kW 5 hp) accessory demand increases the fuel consumption rate from 0.069 to 0.1 ℓ/km over the urban cycle. Under identical conditions in the electric mode, the rate of battery consumption jumps from 0.020 to 0.034 Δs/km or 68 percent.

- The diesel should not be used to power accessories when the propulsion strategy is electric primary drive. Instead, the air-conditioner and other accessories should be powered by the motor, which can be topped by the diesel as necessary. Circumstances exist, however, in which a complete switch from the electric to the diesel modes may be appropriate.

Figure 36* shows expected petroleum consumptions as a function of distance for the Hybrid B using two strategies over the highway cycle.

*This and subsequent figures are based on our recently completed computer program OPSTRAT, a description of which may be found in Appendix A.

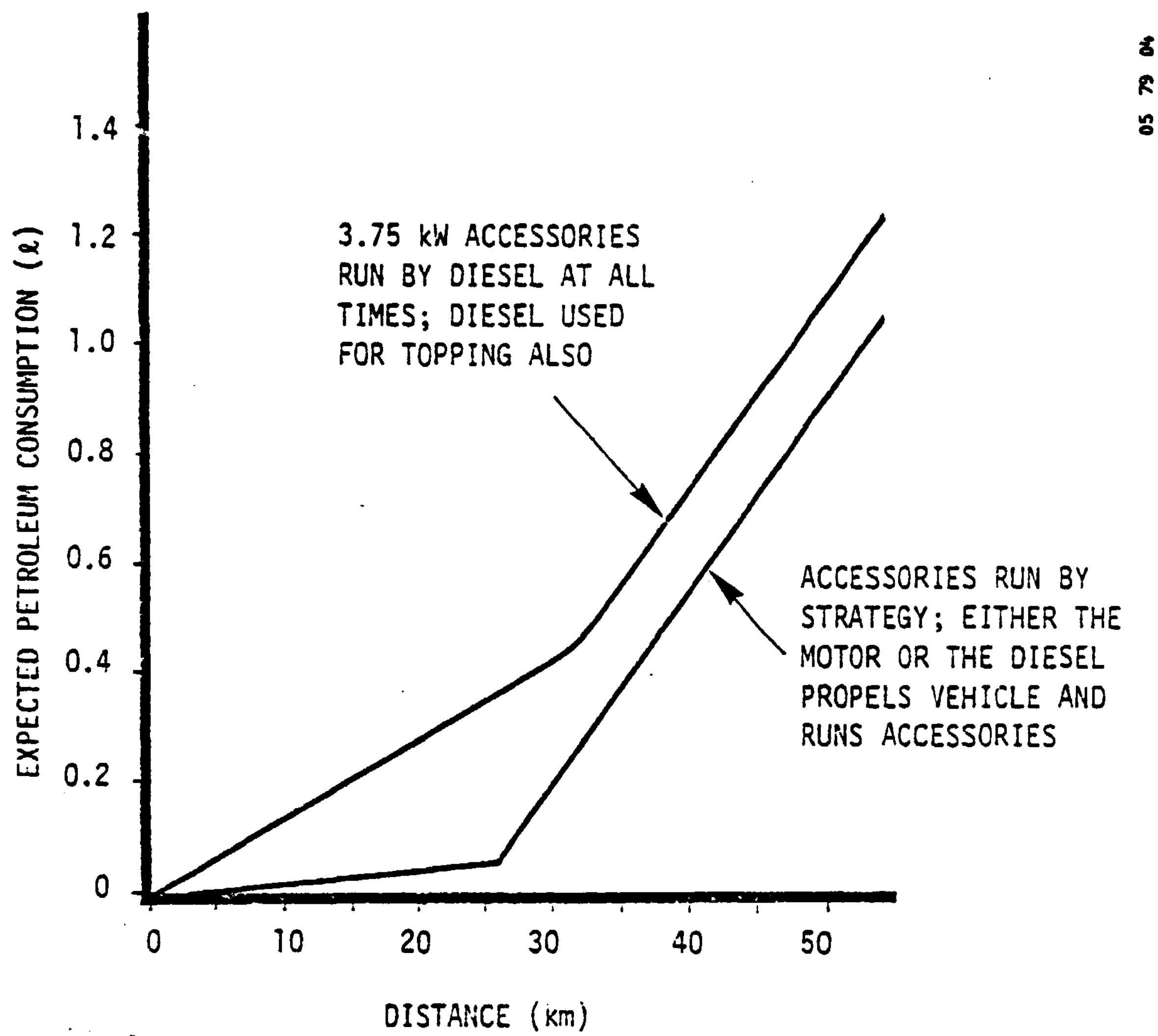


Figure 36. Comparison of Expected Petroleum Consumptions for Two Strategies to Run the Accessories: FHDC

The left line represents the effect of using the diesel at all times, both to power accessories and to top the motor. The right line represents the effect of using the motor to power accessories (and the engine only for topping). Clearly, the latter strategy consumes less petroleum at any distance. A similar result holds for the urban cycle, as is demonstrated in Figure 37.

A related issue is whether there is any merit in using a diesel topped by electric strategy in which the diesel's maximum power is limited to a level below its capabilities - say, between 5 and 15 kW. Figure 38 indicates that such strategies could reduce petroleum consumption, but only if the hybrid travels beyond a rather long distance. Even there, the potential petroleum conservation is not substantial.

11.5 PETROLEUM WORTH

We introduce here the concept of the battery's "petroleum worth" - the fuel savings resulting from discharging the battery 80 percent. This concept will be helpful in situations in which the hybrid's daily activities are sufficiently long and varied that the battery could be discharged in several different ways.

Some petroleum is saved any time the motor is used. The amount saved depends on the specific driving environment and control strategy. For example, the amount of petroleum saved by operating Hybrid A in the electric mode over the highway cycle with its air-conditioner on is 1.96 liters. In contrast, the same battery is "worth" 2.66 liters if it is discharged over the FUDC with the air-conditioner off.

The battery's petroleum worth is a function of three variables: the rate of petroleum consumption while the motor is operating, the rate of petroleum consumption which would occur if the motor were not operating, and the rate of battery consumption. Let these variables be denoted ℓ/km_M, $\ell/km_{(No\ M)}$, and $\Delta S/km$, respectively. Then

$$0.8 \times \left(\frac{\ell/km_{(No\ M)} - \ell/km_M}{\Delta S/km} \right)$$

is the amount of petroleum saved by discharging the battery 80 percent.

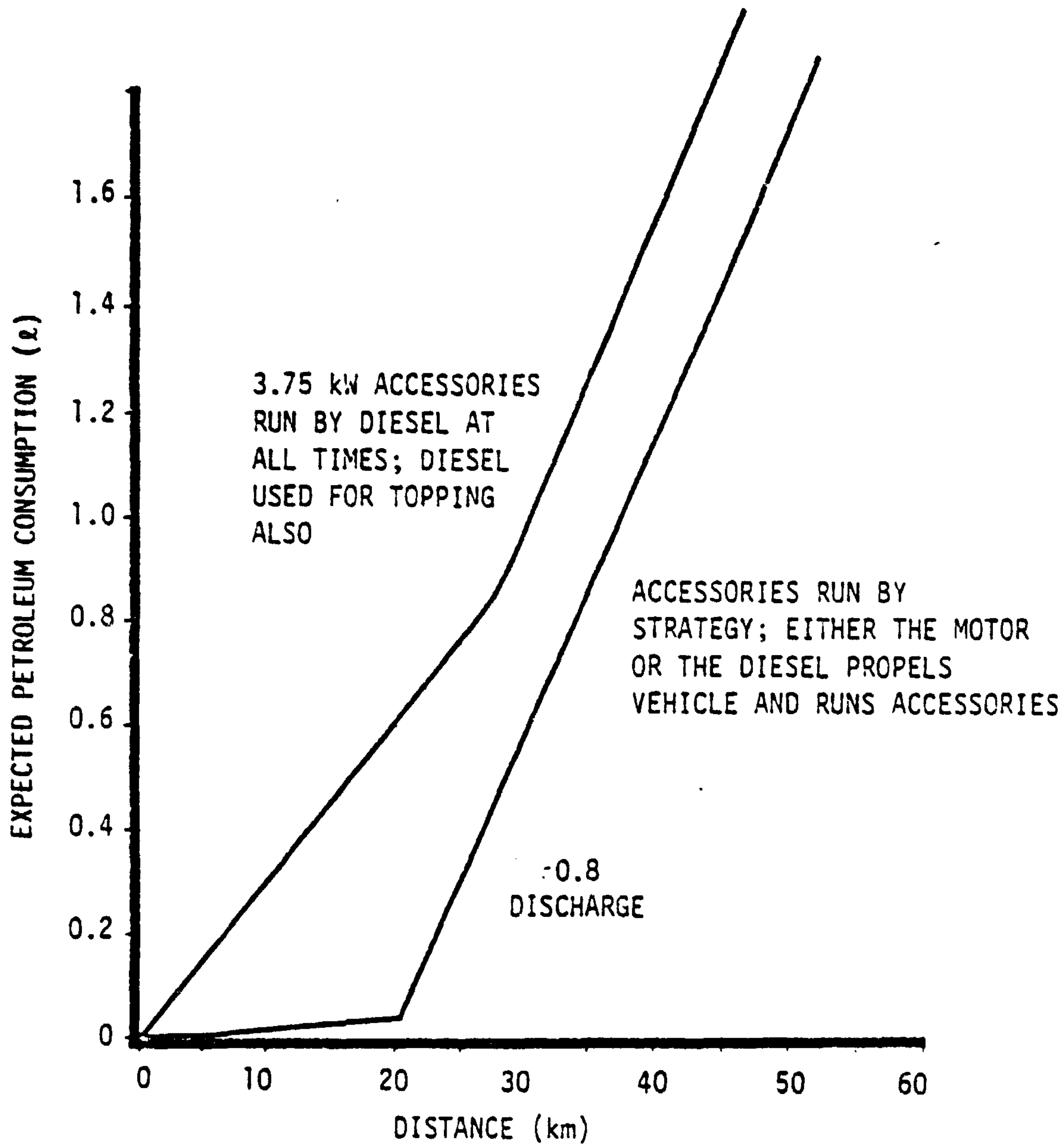


Figure 37. Comparison of Expected Petroleum Consumptions for Two Strategies to Run Accessories: FUDC

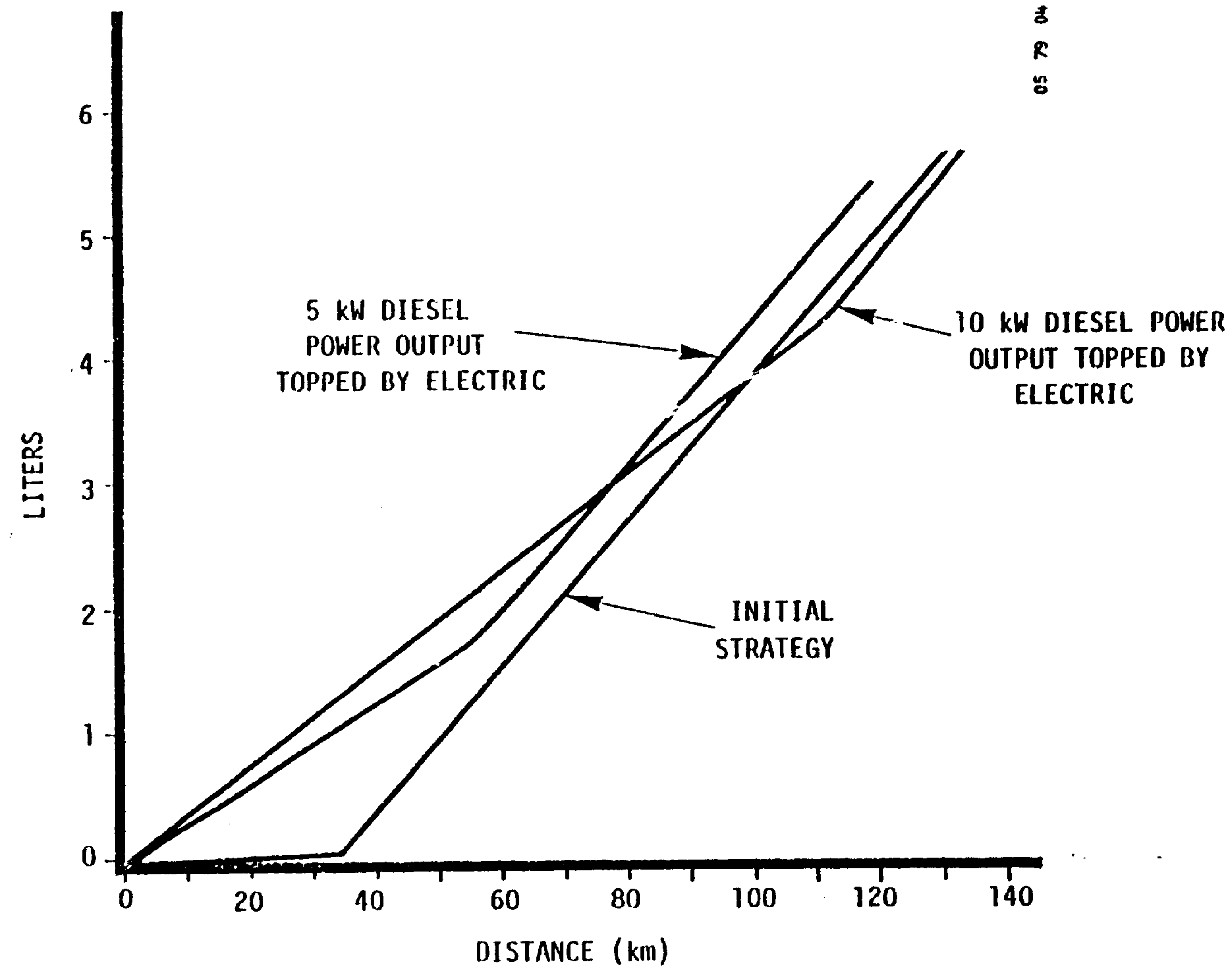


Figure 38. Constant Diesel Power Output with Electric Topping: FHDC

The relative merits of various strategies can now be examined more closely. Associated with every control strategy and type of driving are specific values for rates of consumption before and after discharge. For example, $\ell/km_{(NOM)}$, ℓ/km_M and $\Delta s/km$ are 0.0689, 0.00209, and 0.0201, respectively, for Hybrid A operating over the FUDC under the initial strategy. The battery's petroleum worth under such conditions is

$$0.8 \times \left(\frac{0.0689 - 0.00209}{0.0201} \right) = 2.66 \text{ liters.}$$

We have performed similar calculations for a variety of strategies and driving conditions. The results are presented in Figure 39.

Figure 39 makes clear that the amount of petroleum saved by using the motor rather than the engine depends on the task to be performed. The highest recorded petroleum worth is 2.83 liters, which occurs when the motor is restricted to a maximum power of 15 kW while operating over the FUDC with no air-conditioning. The lowest recorded value, 1.96 liters, occurs over the FHDC with the air-conditioner on. The difference in these petroleum worths is a substantial 31 percent.

11.6 POTENTIAL NATIONWIDE SAVINGS OF A SOPHISTICATED ON-BOARD STRATEGY: OMNISCIENT AND INITIAL STRATEGIES AVERAGED OVER MISSION A

The expected petroleum consumptions over Mission A for the initial and omniscient strategies are computed in Table 36. Mission A is characterized by a distance distribution, in which each distance is divided into proportions of highway and city driving. (The SAE segments used elsewhere are assumed here to be FUDC segments.) Expected petroleum consumptions at specific distances are averaged over the distribution to form composite mean fuel consumptions for both strategies.

There are, of course, any number of ways in which small segments of highway and urban driving could be combined to yield the designated proportions. For simplicity, we assume that, at a given distance, either a single highway segment follows a single urban segment, or a single urban segment follows a single highway segment. Each possibility occurs 50 percent of the time.

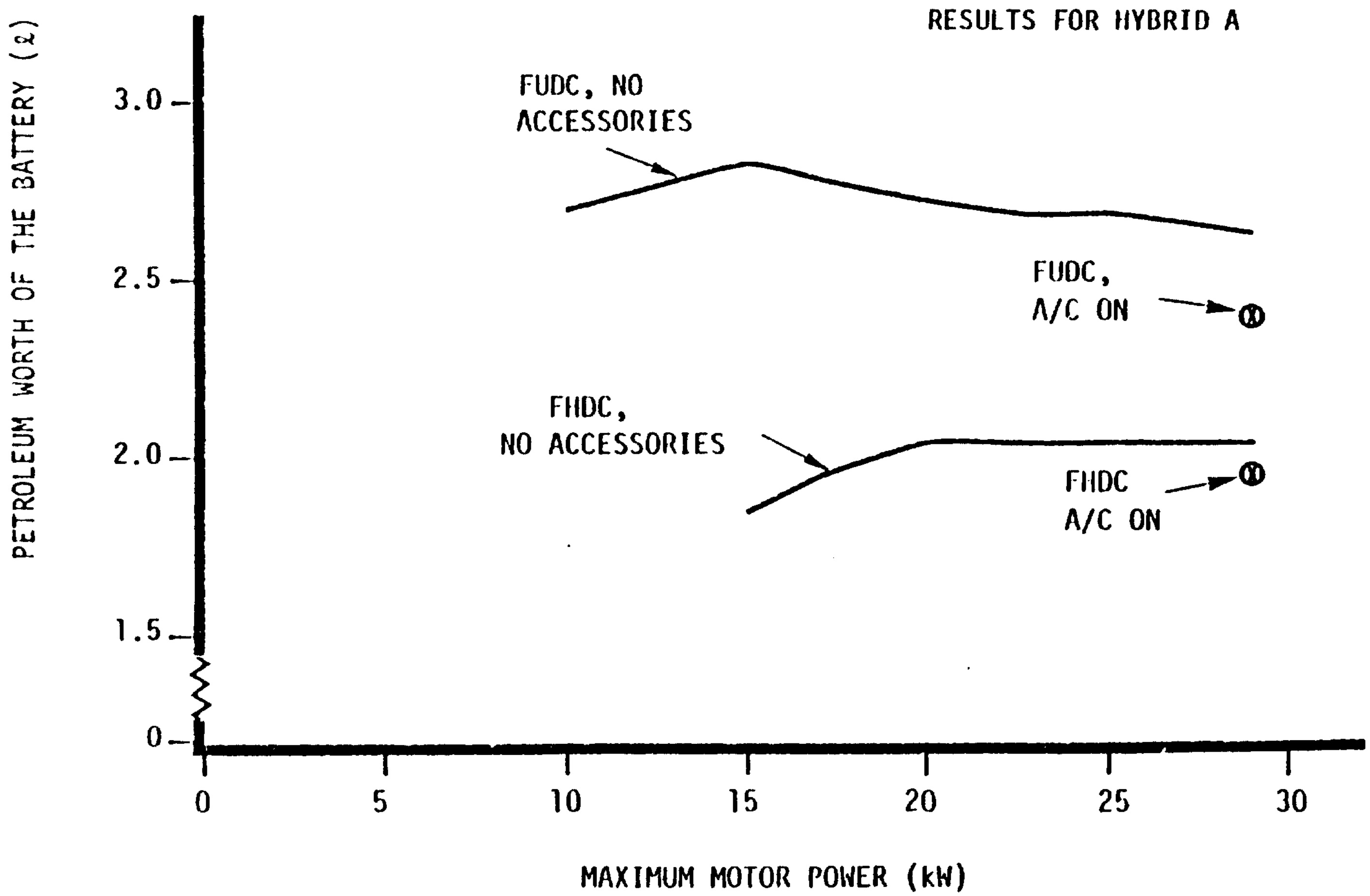


Figure 39. Battery Petroleum Worth as a Function of Strategy and Driving Cycle

Table 36. Initial and Omniscient Strategies Averaged Over Mission A

Daily Travel (km)	Prob.	Highway Travel (km)	Urban Travel (km)	Average Liters Consumed: Omniscient Strategy	Initial* Strategy
9	.25	0	9	.019	.019
22	.25	0	22	.046	.046
45	.25	7	38	.296	.359
71	.1	31	40	1.67	1.76
96	.05	59	37	2.95	3.23
141	.05	115	26	5.34	5.48
231	.04	231	0	9.77	9.77
372	.01	372	0	17.0	17.0

Omniscient Strategy: .308   Reduction = .014 liter

Initial Strategy : .322   = 4.34%

*Assumption here is that the highway portion follows the urban portion 50% of the time, and the urban portion follows the highway portion 50% of the time.

The order of segments has no effect on the omniscient strategy, which withholds use of the motor until conditions are most advantageous. The less discriminating initial strategy, however, consumes substantially more fuel if the highway segment precedes the urban. The petroleum consumption listed under the initial strategy at each distance is the average of the fuel consumed when the urban precedes the highway segment and that consumed when highway precedes urban.

The effect of air-conditioning is not included in the calculation, primarily because we do not envision many circumstances under which the air-conditioning would dictate withholding motor use. Such a move could only be based on a very high probability of a later, more advantageous period for battery discharge, which would be difficult for the onboard strategy (described in Subsection 11.1) to predict.

We estimate, then, that the omniscient strategy consumes an average of approximately 5 percent less petroleum over Mission A than does the initial strategy. This estimate is reasonably accurate. We may eventually use a more detailed distributional approach to obtain a statistical estimate of the benefit.

We are currently constructing an on-board strategy which will conserve as much petroleum as possible. The task here is to use historical and driver supplied information to produce an on-board strategy which resembles as closely as possible our final version of the omniscient strategy.

SECTION 12

NTHV MICROPROCESSOR SYSTEM

12.1 SYSTEM OVERVIEW

In order to obtain the optimal petroleum economy for the hybrid vehicle, the vehicle's operation must be carefully controlled at all times. The motor and engine have to be monitored and regulated to their optimal speeds, and the transmission must match these speeds and the power to the drive wheels. This must be done constantly, and adjustments made as necessary, any time the vehicle is in use.

In order to optimally control the vehicle in this manner, a digital microprocessor system will be installed in the vehicle. A control strategy will be developed for each subsection of the entire vehicle, and the microprocessor system will be responsible for the implementation of this group of strategies. In addition, the system will perform other tasks, such as built-in testing, to enhance public acceptance of the vehicle.

The microprocessor control system is composed of the functional units shown in Table 37. These units work together and share information. Each unit corresponds to one independent computer program or major subroutine. Each communicates with the others that need its output or produce inputs. In this manner, each unit runs at its own speed, asynchronously with other units, and communicates with them as necessary. The inputs to each function are data either from a sensor (Table 38) in the vehicle, or from another function. Likewise, outputs are either to actuators (Table 39) in the vehicle or to other units. Locations will be reserved in memory for these transfers. To send data to another function, a function will write it in a predefined location. Without requiring synchronization.

The functional units listed in Table 37 are described in more detail in the next section. The implementation of the computer system is described in Section 12.3.

Listed with each function in Section 12.2 are the inputs and outputs, along with their sources or destinations and the sampling rate for inputs. We have given rough estimates for the memory required for each function (Table 40) and for the frequency with

Table 37. Functional Divisions

Powerplant
Internal combustion engine
Electric motor and battery
Transmission
Display
Braking (subfunction to Powerplant)
Climate control
Radio control
Restraint control
Built-in test
Shifting (subfunction to powerplant)
Battery charging

Table 38. Sensors (Inputs)

Acceleration pedal
Brake pedal
Gear selection
I.C. Engine speed
I.C. oil temperature
I.C. water temperature
I.C. oil pressure
I.C. oil level
I.C. fuel level
Throttle or diesel fuel control
Motor speed
Motor temperature
Armature current
Field current
Battery charge
Battery temperature
Battery fluid level
Transmission gear
Engine clutch
Motor clutch
Converter lock-up
Transmission output start speed
Transmission oil level
Transmission oil temperature
Input light levels
External light levels
Right front brake pressure
Right front wheel speed
Left front brake pressure
Left front wheel speed
Right rear brake pressure
Right rear wheel speed
Left rear brake pressure
Left rear wheel speed
Outside air temperature No. 1
Outside air temperature No. 2
Interior air temperature No. 1
Interior air temperature No. 2
Radio frequency
Radio output
Bumper impact
Firewall impact
Seat occupied sensor

Table 39. Actuators (Output)

Throttle or diesel fuel control
I.C. engine start switch
Glow plugs (diesel)
Spark plugs (gas)
Fuel injections (gas)
Motor field current
Motor start switch
Engine clutch
Motor clutch
Converter lock-up
Transmission gear selector
Digital displays
Display intensity
Light switches
Right front brake pressure
Left front brake pressure
Right rear brake pressure
Left rear brake pressure
Heater
Air conditioner
Battery heater
Defroster
Radio Tuning
Radio Gain
Driver air bag activator
Passenger air bag actuator
Battery charger

Table 40. Summary of Memory Space

Function	Size (Bytes)
Powerplant	2048
I.C. Engine	2024
Motor	1024
Transmission	1024
Display	512
Braking	1024
Climate Control	256
Radio Control	256
Restraint Control	256
Built-in Test	0496
Shifting	1024
Battery Charger	256
Total Memory	12,800

which each function must be executed. It must be emphasized, however, that these estimates are preliminary. Estimates of computer speed and memory depend not only on the algorithms chosen, but also on their implementation. Accuracy requirements, types of sensors and actuators, and the microprocessor instruction set also influence memory and execution time.

Figures 40 through 43 constitute a functional block diagram of the NTHV microprocessor system. Figure 40 illustrates the interconnections of the powerplant and drive functions. Figure 41 shows the display, radio control, and climate control, Figure 42 the restraint and charging function, and Figure 43 the built-in test function.

12.2 BRAKING FUNCTION

Rather than detailing the structure of each function unit, we have chosen one particular unit as an illustration. The braking function is sufficiently complex to show the parameters which have to be taken into account in devising a microprocessor system.

The purpose of the microprocessor's braking unit is to integrate the hydraulic, regenerative and engine braking so that the vehicle may be smoothly slowed or stopped. As the driver releases the accelerator and steps on the brake, the microprocessor must control the motor and/or engine speed and switch the motor to regenerative braking. Since regenerative braking applies only to the drive wheels, the microprocessor must also regulate the hydraulic pressure on the front and rear wheels independently. The same braking unit will also be integral to anti-skid braking, since it already controls the necessary sensors and actuators.

The routine must look at the status of the motor, battery, engine and transmission, as well as the hydraulic pressure to the brakes. It is called by the powerplant function and returns the amount of regenerative braking needed. The powerplant function then calls the shifting function to determine which gear is to be used. Finally, the proper commands are sent to the motor, engine and transmission functions. Any problems are noted and reported to the built-in test routines for appropriate action.

The status of the pressure on the brake pedal, the hydraulic pressure, in the brakelines and the ground speed has to be checked every 0.1 second. The motor, battery, engine, and transmission status will only require monitoring every 10 seconds. We estimate

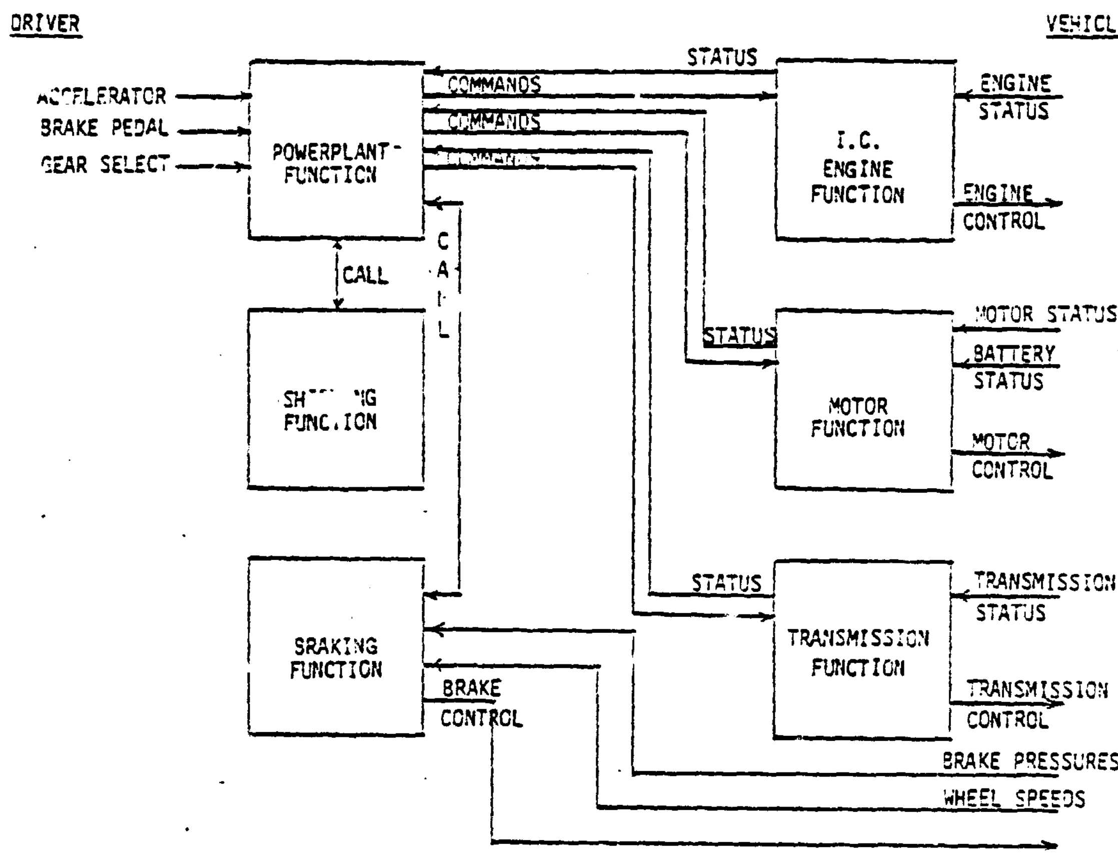


Figure 40. Powerplant and Drive Train Control

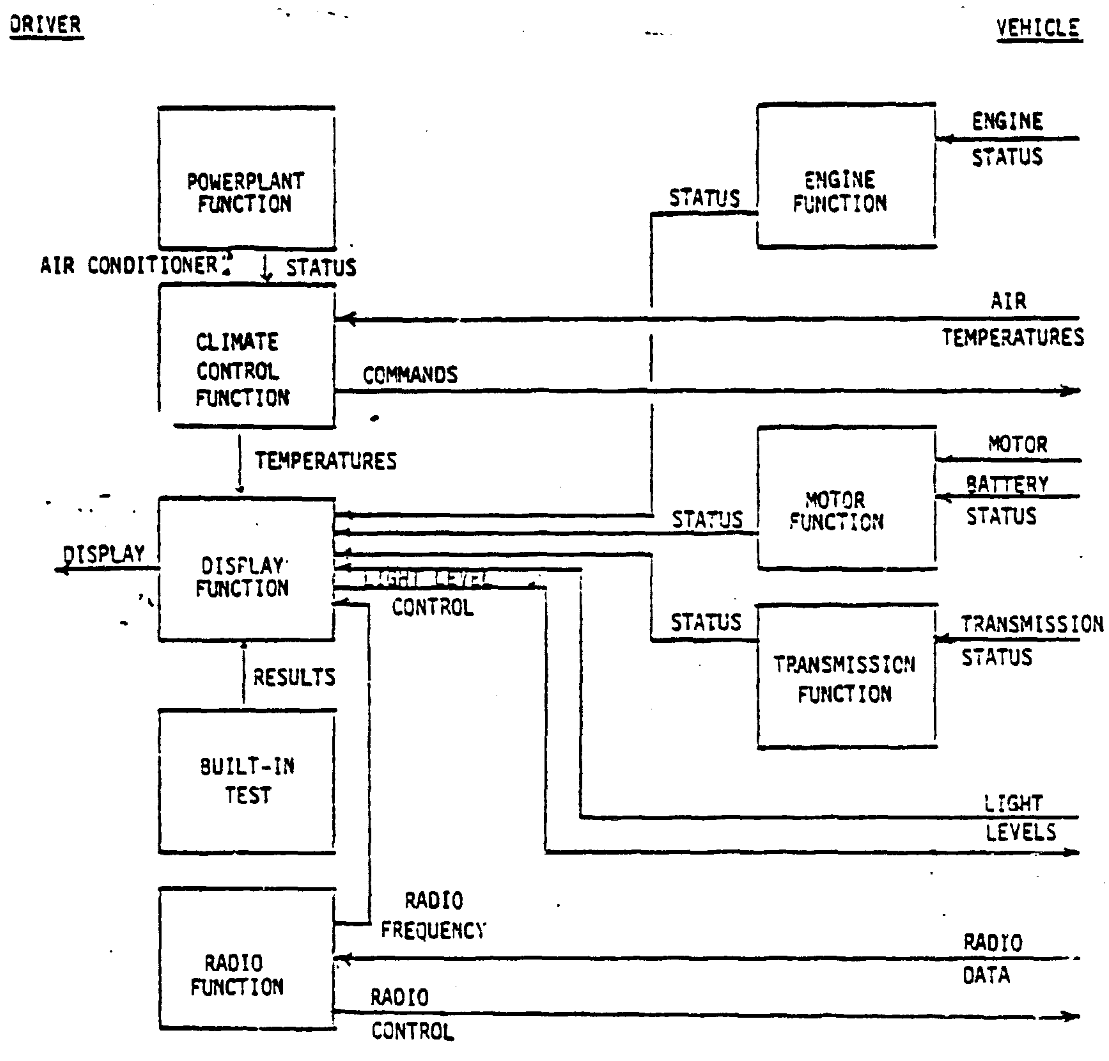


Figure 41. Display, Radio, and Climate

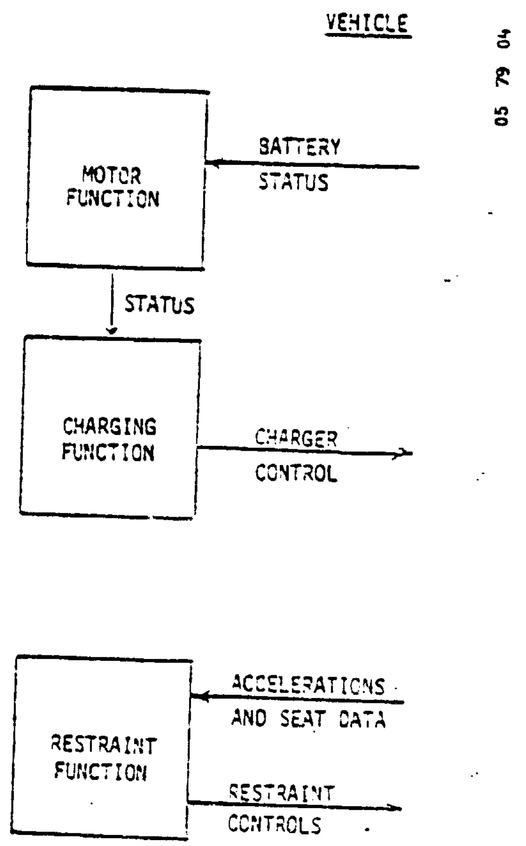


Figure 42. Restraint and Charging

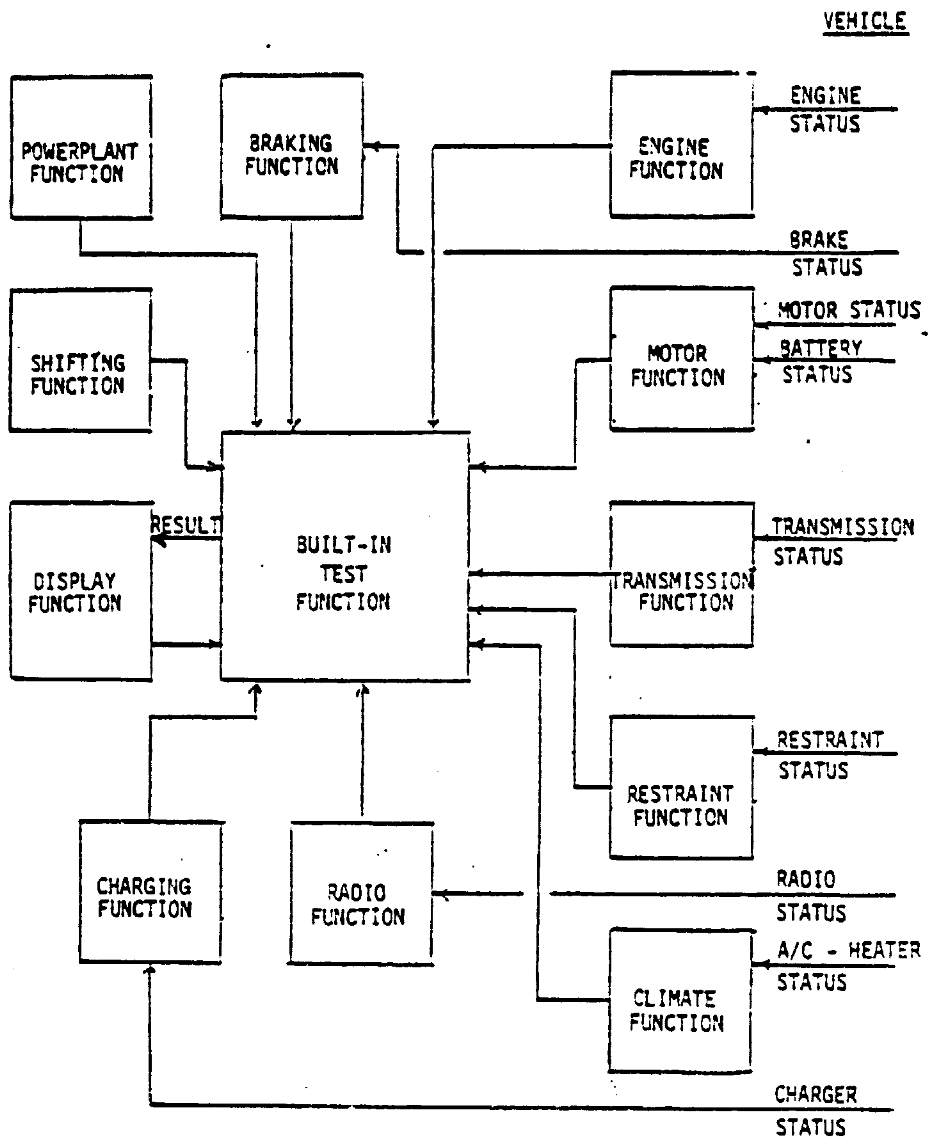


Figure 43. Built-in Test Function

that 1024 bytes of memory will be required for this routine. Its inputs and outputs are listed in Table 41.

12.3 SYSTEM IMPLEMENTATION

There are two overall methods by which the microprocessor system can be implemented. The centralized approach would have one microprocessor perform all functions. This would make communication between functions simple data sharing, but would require a fast microprocessor with a large address space. The distributed approach, on the other hand, would split the functions into two or more microprocessors. Each processor would require a small amount of memory and would not be as fast as a single central unit. If one microprocessor failed, the distributed approach would allow another to assume the functions of the failed unit, at a lowered capability. A centralized microprocessor would not have this capability.

The distributed approach allows the use of slower off-the-shelf units. The price of a set of these units sufficient to perform all of the tasks required would be much lower than that of a single, custom microprocessor.

As currently envisioned, the production system for the NTHV consists of three microprocessors, their supporting circuits , double space 16,384 bytes of memory, power supplies, sensors, actuators and interface circuits. The system has 44 sensors and 15 actuators. We estimate the production quantity (100,000 units per year) cost of the total system to be around $426. This estimate, of course, will be updated as the control algorithms and types of sensors and actuators are finalized.

The development of the microprocessor will involve the trial of many different algorithms, sensors and actuators. This requires a system that can be changed quickly. It is much harder to rapidly change a distributed system, so for the development phase we will use a single fast processor with floppy disks, CRT terminal and a printer. One or more compatible smaller processors will be used to test the distributed approach. These processors will be loaded and controlled by the operator through the central computer. The main processor will bring in programs, compile and link those programs, and download them onto the satellite processors. Then, as the satellite processors run the vehicle, the central processor can monitor the test and display the results. This will allow the operator almost instant answers to any test he wishes to make on

Table 41. Inputs and Outputs of the Braking Function

Inputs	Source	Units	Sampling Rate
Motor speed	Passed From Powerplant Function	rpm	60 sec
Motor temperature		°C	10 sec
Engine speed		rpm	10 sec
Engine oil temperature		°C	10 sec
Engine water temperature		°C	10 sec
Engine oil pressure		N/cm^2	10 sec
Transmission current gear		Gear no.	10 sec
Transmission oil temperature		°C	10 sec
Brake pedal position		Degrees	0.1 sec
Vehicle ground speed		km/hr	0.1 sec
Right front brake pressure	pressure sensor	N/cm^2	0.1 sec
Righr front wheel speed	speed sensor	rpm	0.1 sec
Left front brake pressure	Pressure sensor	N/cm^2	0.1 sec
Left front wheel speed	Speed sensor	rpm	0.1 sec
Right rear brake pressure	Pressure sensor	N/cm^2	0.1 sec
Right rear wheel speed	speed sensor	rpm	0.1 sec
Left rear brake pressure	Pressure sensor	N/cm^2	0.1 sec
Left rear wheel speed	Speed sensor	rpm	0.1 sec

Outputs	Destination	Units
Right front brake pressure	Pressure Regulator	N/cm^2
Left front brake pressure	Pressure regulator	N/cm^2
Right rear brake pressure	Pressure regulator	N/cm^2
Left rear brake pressure	Pressure regulator	N/cm^2
Desired regenerative braking	Powerplant function	Amps
Braking status	Built-in test	Go/no go

the development vehicle. The results can be logged onto the floppy disk for comparison to other configurations of the vehicles or to other algorithms.

SECTION 13

EFFECT OF VEHICLE WEIGHT

The effect of vehicle weight on the performance characteristics of an NTHV was investigated by using a particular heat engine/ electric motor/battery package system. This system consisted of a 24 kW electric motor, a 44 kW heat engine and a lead-acid battery package with a 12.6 kW-hr capacity. The weight variations under consideration are given in Table 42.

Table 42. The NTHV Inertia Weight Variations

NTHV Inertia Weight [kg (lb)]	Power to Weight Ratio [kW/kg (hp/lb)]
1364 (3000)	0.0499 (0.0304)
1531 (3500)	0.0327 (0.0261)
1800 (3960)	0.0378 (0.0231)
2045 (4500)	0.0333 (0.0203)
2273 (5000)	0.0299 (0.0182)

Table 43 shows the effects of these weights on the system package when it is taken through Mission A. The effect of weight on annual petroleum consumption is much more significant than the effect on annual electricity consumption. The linear increase of annual fuel consumption with inertia weight is illustrated in

Table 43. Effect of Vehicle Inertia Weight on Hybrid Performance Parameters

Hybrid Inertia Weight kg (lb)	Annual Petroleum Consumption (ℓ)	Petroleum Economy (km/ℓ)	Annual Electricity Consumption (kW-hr)	Electricity Economy (km/kW-hr)	Electric Range (km)
1364 (3000)	363	51.21	3035	6.13	44.3
1591 (3500)	450	41.34	3144	5.91	39.1
1800 (3960)	540	34.42	3225	5.77	35.9
2045 (4500)	640	29.07	3339	5.57	32.2
2273 (5000)	738	25.19	3383	5.50	32.2

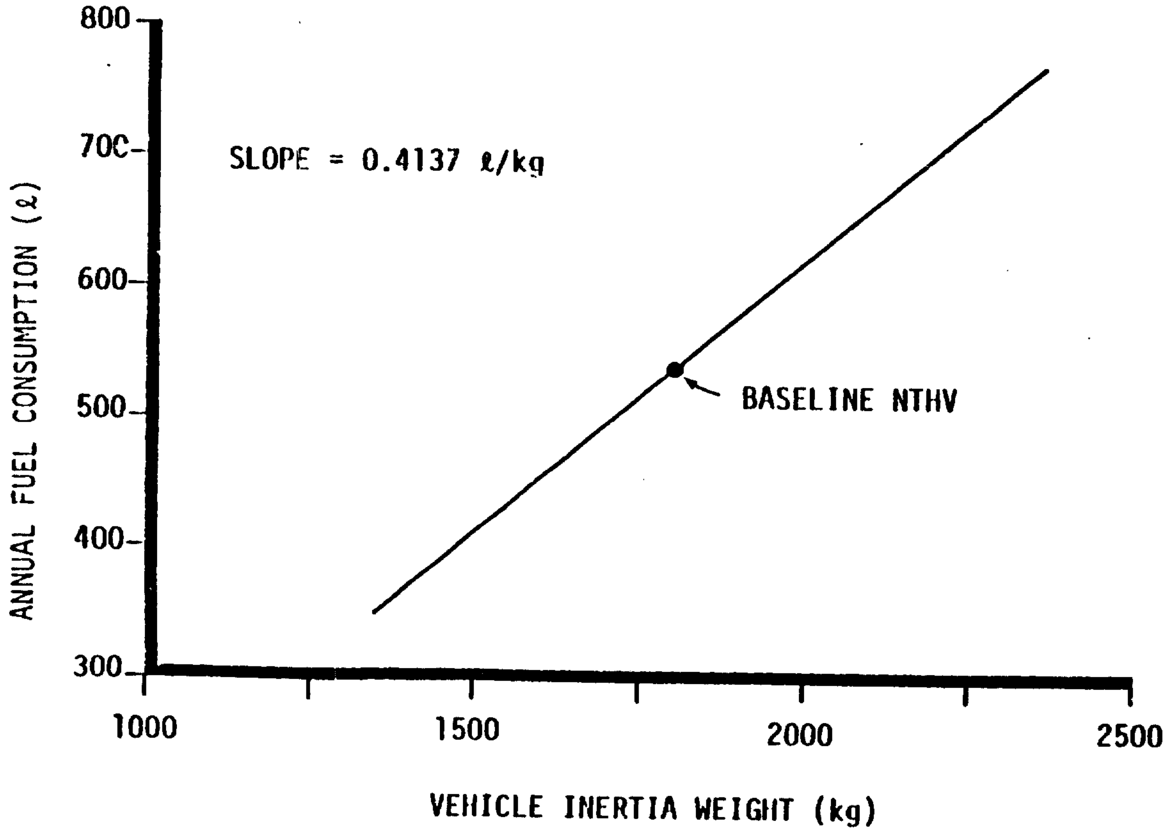


Figure 44. Effect of Vehicle Inertia Weight on Annual Fuel Consumption

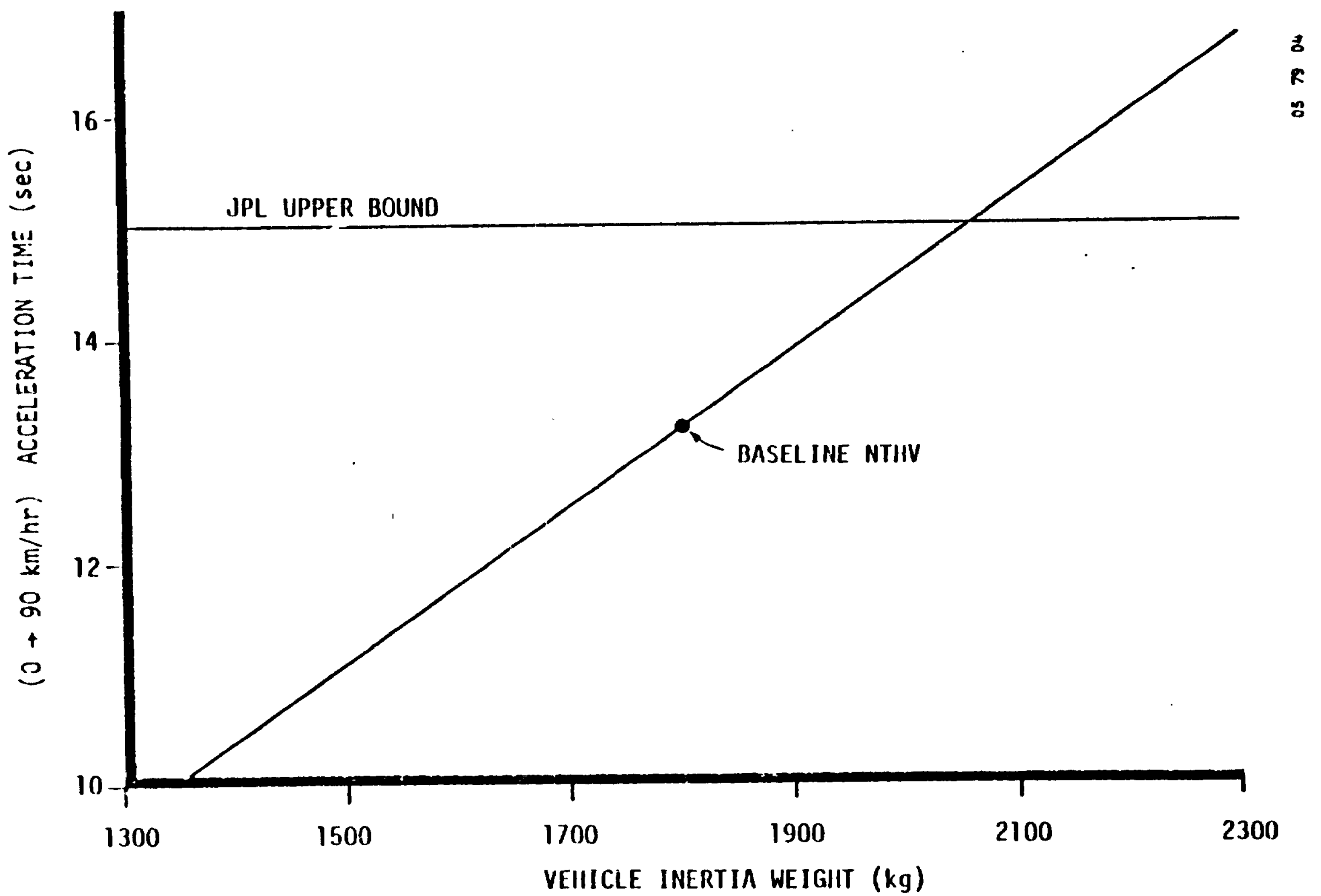


Figure 45. Effects of Vehicle Inertia Weight on Acceleration Capabilities

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Figure 44. Figure 44 shows that 0.4137 liters of petroleum can be saved in a year for every kilogram of weight reduction in the hybrid vehicle.

The effects on acceleration capability are illustrated in Figure 45. The baseline NTHV does better than the minimum JPL acceleration requirements.

SECTION 14

THE EFFECTS OF AIR DRAG RESISTANCE

The effects of air drag resistance on petroleum consumption and on electric range for the baseline NTHV are shown in Table 44.

Table 44. Effects of Air Drag Resistance on the Main Parameters of the Baseline NTHV

Drag Factor C_D x Area (m^2)	Annual Petroleum Consumption (ℓ)	Electric Range (km)	Life Cycle Costs (1978$)
0.76*	540	36.0	24,495
0.84	571	34.9	24,574
0.92	602	34.2	24.753

*Projected drag factor of the baseline NTHV.

A 10 percent increase in the drag coefficient has a 6 percent penalty in annual petroleum consumption and a 3 percent penalty in electric range of the baseline NTHV. The GM X body has a drag coefficient of 0.417. Further efforts on restyling the X body would not be productive, but aerodynamic drag should be improved in the design studies by minor modifications, such as a rounded nose, rounded rear corners, etc.

EFFECTS OF ROLLING RESISTANCE

The effects of rolling resistance on the baseline NTHV were also investigated. The results are given in Table 45.

A 14 percent increase in the rolling resistance has a 9 percent penalty in annual fuel consumption and a 6 percent penalty in electric range of the baseline NTHV. The tire companies are actively working on tire designs to achieve minimum rolling resistance and extended tread life. With tire company cooperation, it will be possible to equip the NTHV with developmental, non-production, next generation tires and gain the benefits of the latest state of the art.

Table 45. Effects of Rolling Resistance on the Main Parameters of the Baseline NTHV

Rolling Resistance Coefficient (1/kg)	Annual Petroleum Consumption (ℓ)	Electric Range (km)	Life Cycle Costs (1978$)
0.0271*	540	36.0	24,495
0.0308	589	33.9	24,631

*Projected coefficient for the baseline NTHV

SECTION 15

ACCELERATION, GRADEABILITY AND ELECTRIC RANGE OF HYBRID VEHICLES

The acceleration and gradeability of the hybrid vehicles were studied in three different modes: heat engine alone, electric motor alone, and hybrid.

PERFORMANCE OF THE HEAT ENGINE ALONE

The acceleration curve of the baseline NTHV with diesel drive alone (Figure 46) is typical of most internal combustion engine vehicles which do not have torque converters. The acceleration of the vehicle rises to a maximum near the torque peak of the engine and drops off toward the maximum rpm. In this particular diesel the torque peak occurs at 3000 rpm, and the maximum power of the engine occurs at 5000 rpm, the maximum engine speed.

The acceleration of the baseline NTHV on diesel power alone is moderate, having a 0-80 km/hr acceleration time of over 16 seconds, slower than almost all passenger cars on U.S. highways. This is a result of a low power to weight ratio, together with a low N/V (ratio of engine speed to vehicle speed). This combination yields extremely good fuel economy, but marginal acceleration for overall vehicle use. However, the hybrid's capability of adding the output of the electric motor to that of the diesel allows it much better performance than it has with the diesel alone.

PERFORMANCE OF THE ELECTRIC MOTOR ALONE

The acceleration curve of the baseline NTHV with electric drive alone (Figure 47) has a totally different appearance from the acceleration curve with the diesel alone (Figure 46). With the exception of the starting acceleration at half voltage (the far left curve), the acceleration curves for all five gears are very much alike. In fact, it is extremely difficult to find differences between the accelerations in third, fourth and fifth gears at speeds above 70 km/hr. This is entirely due to the output characteristics of the electric shunt motor running above its base speed. A shunt motor is basically a constant power output device, so its torque curve is essentially hyperbolic. Since the power output is almost the same in each gear, the differences in acceleration between different gear ratios at a given vehicle speed are primarily the differences in driveline efficiency and

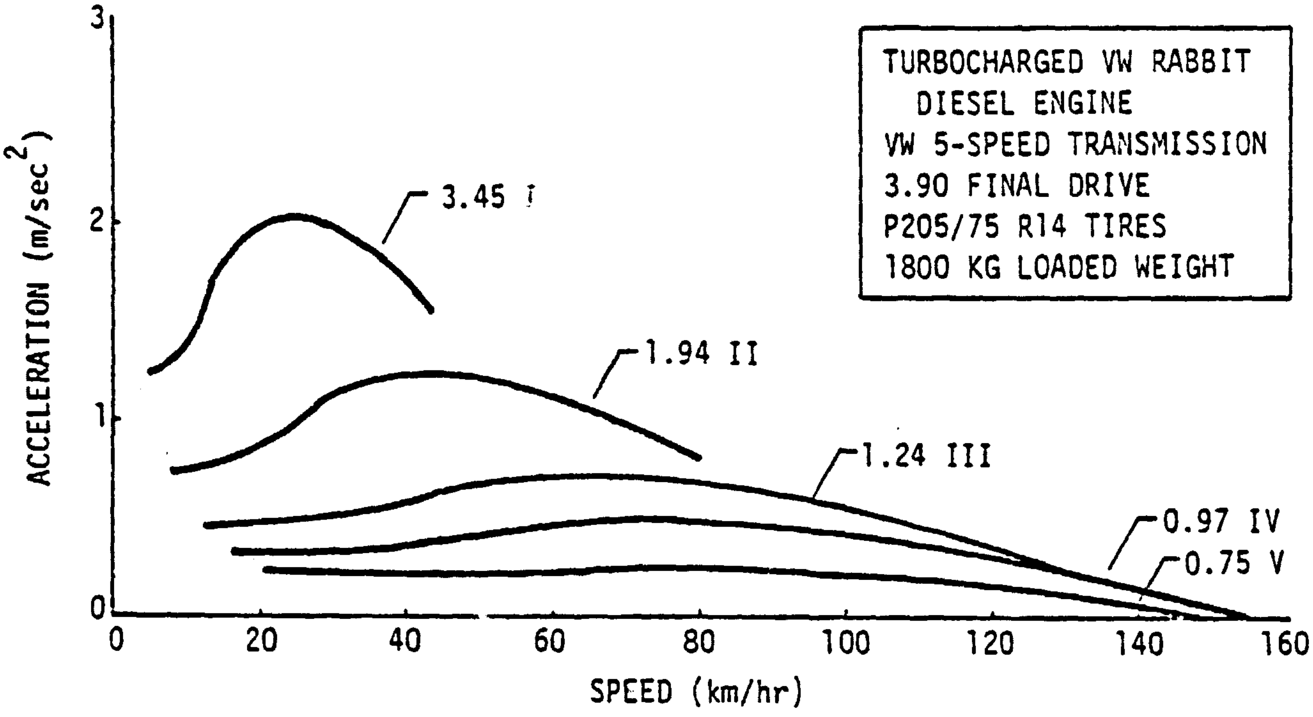

Figure 46. Acceleration Curves (Diesel Drive)

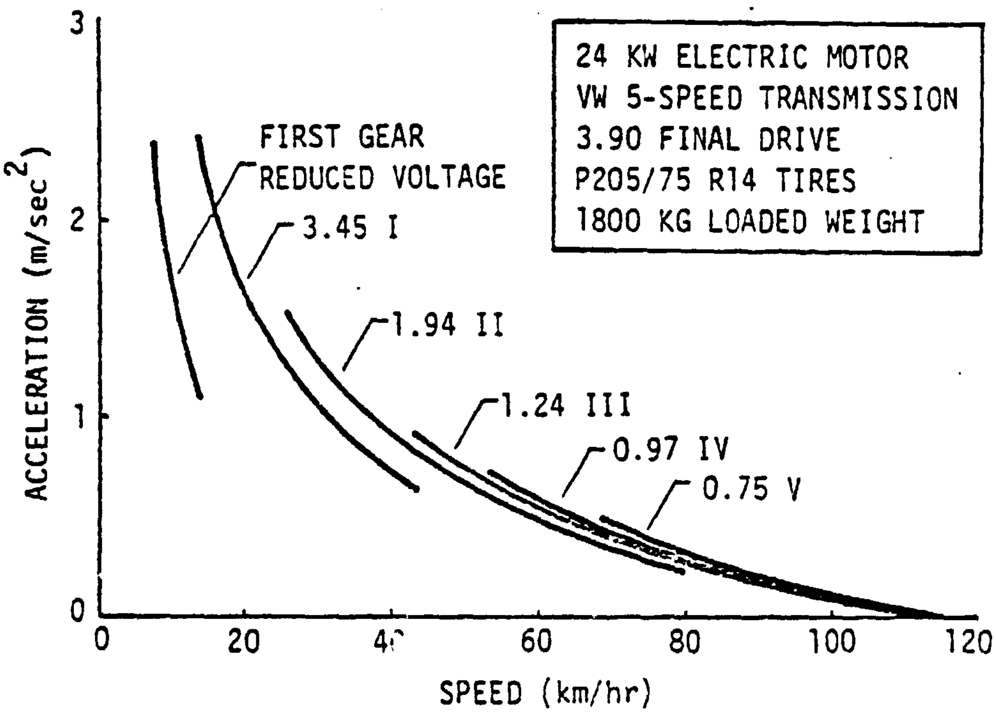

Figure 47. Acceleration Curves (Electric Drive)

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inertia losses (greater in the lower gears). The inertia losses are those portions of the power plant output that are used to provide the angular accelerations of the motor or engine, flywheel, clutch, transmission, final drive, and the wheels and tires. Of course, the power used to accelerate these components is not available to accelerate the vehicle. Usually the engine/transmission portion of the inertia losses are the greatest - particularly in the lower gears, since these losses vary as the square of the overall gear ratio of the transmission and final drive. For this particular vehicle the inertia losses result in a 2.5 percent acceleration loss in fifth gear and a 20 percent acceleration loss in first gear.

Except for low speeds, the NTHV's acceleration in electric drive alone is poor. It is better than the diesel up to approximately 20 km/hr, but drops off rapidly above that speed. It has a 0-80 km/hr time of almost 30 seconds and a 0-50 km/hr time of almost 12 seconds. This is sufficient acceleration for city driving, but is clearly inadequate for the highway.

HEAT ENGINE AND ELECTRIC MOTOR HYBRID PERFORMANCE

The acceleration curve of the electric/diesel combination (Figure 48) is essentially the sum of the other two acceleration curves. Since the sum of the electric and diesel torque curves is almost a straight line. The far left portion of the acceleration curve is the starting torque of the electric motor at reduced voltage added to the torque of the diesel engine.

The acceleration with the combined electric/diesel driveline is much better than that with either of the power plants separately. The 0-80 km/hr acceleration time is reduced to slightly more than 10 seconds. The acceleration of this vehicle with the combined electric/diesel drive is in keeping with a large percentage of the vehicles on the road today, and exceeds the acceleration minimums specified for this program[12].

Figure 49 is a plot of speed versus time and distance versus time for the three driveline combinations. These times and distances were calculated from the acceleration curves in Figures 46 through 48. A shift time of 0.5 seconds, typical of a well shifted manual transmission, was allowed for each shift. In the diesel and electric/diesel configurations the vehicle is started in first gear and shifted through each gear in succession at the maximum engine/motor speed (5000 rpm). In the electric configuration

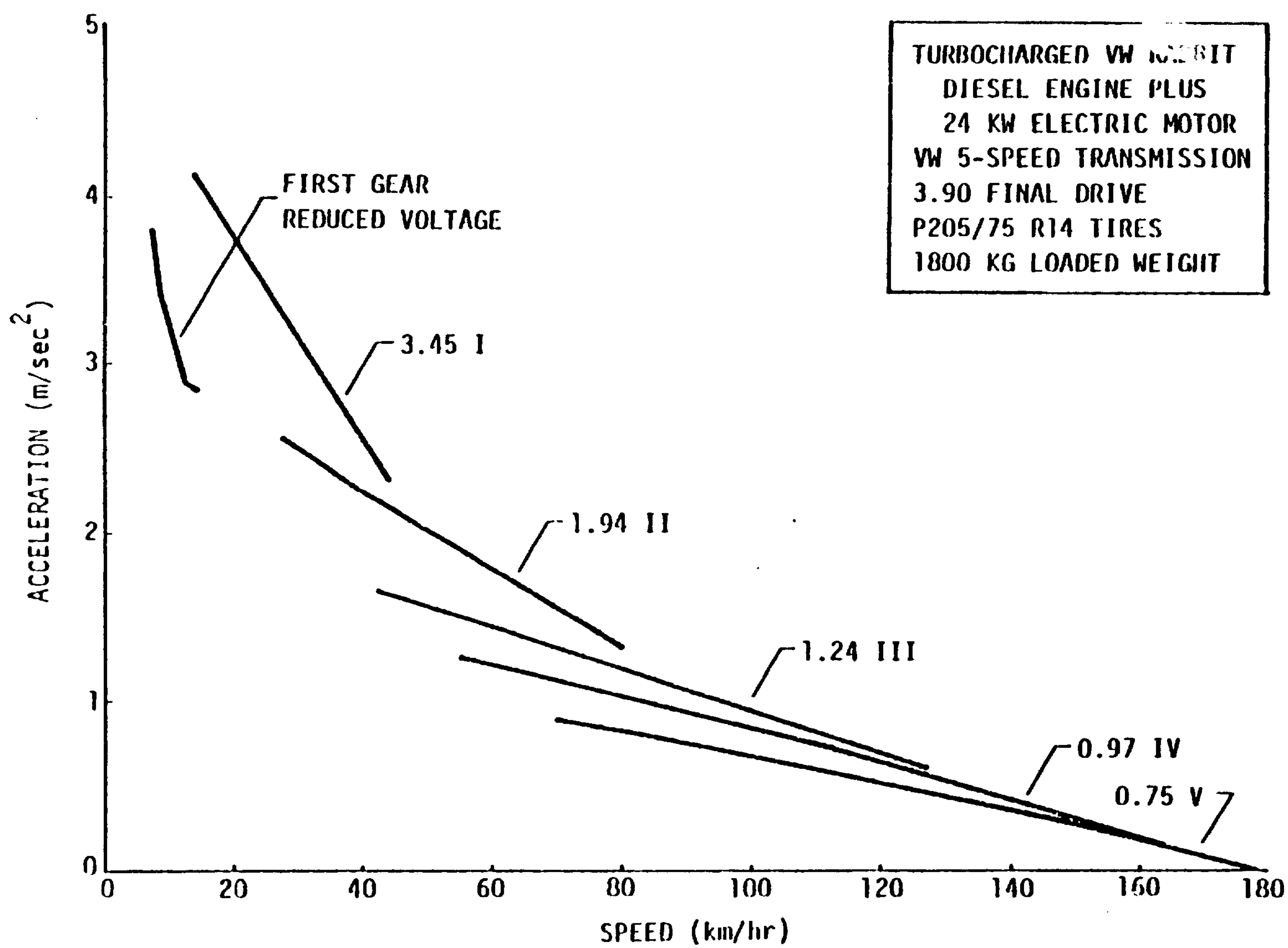

Figure 48. Acceleration Curves (Combined Electric and Diesel Drives)

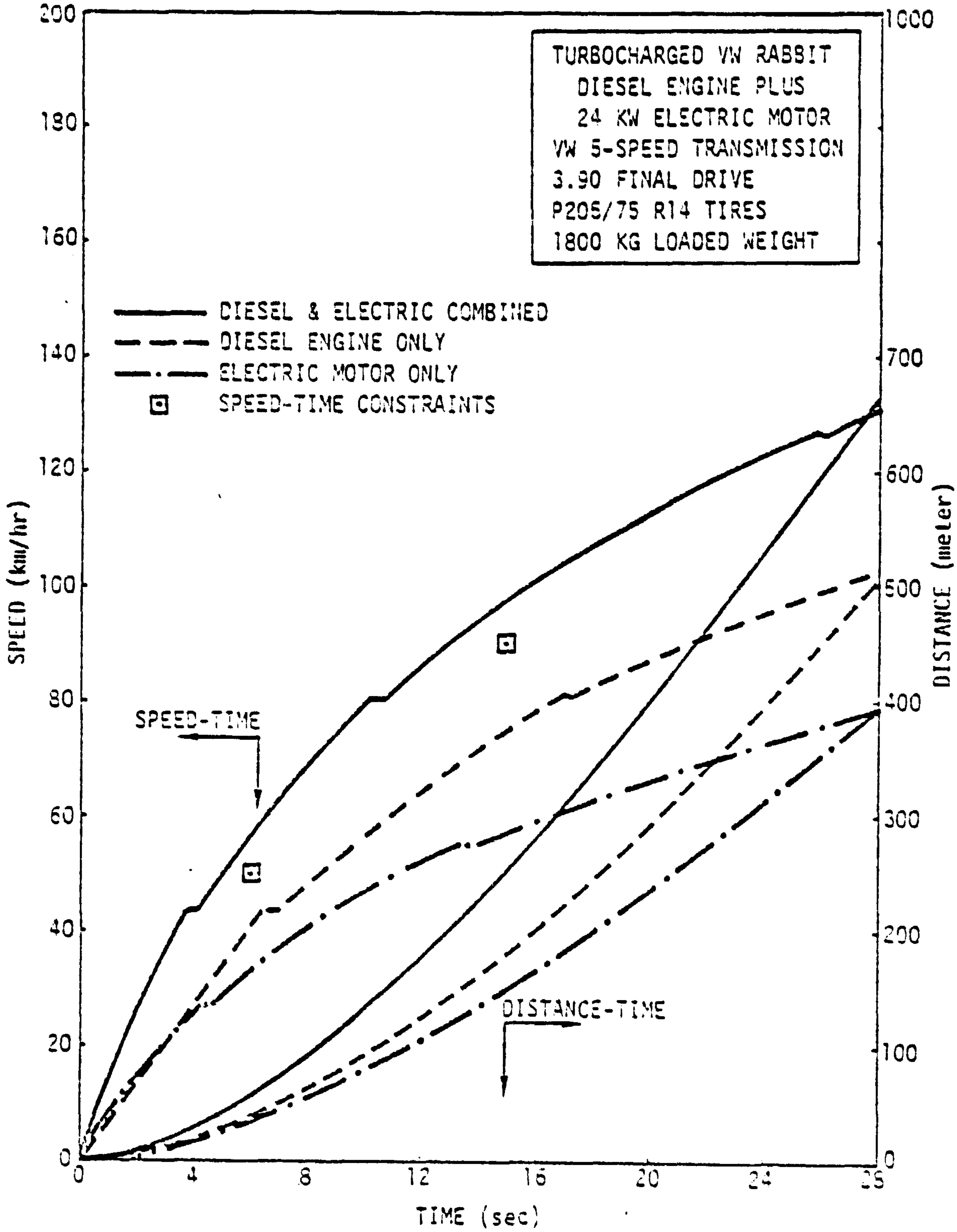

Figure 49. Speed Versus Time and Distance Versus Time

the vehicle is started in first gear and shifted to second as soon as it reaches 27 km/hr, the speed equivalent to the base motor speed in second gear, and then is shifted directly to fourth at 55 km/hr, the base speed in fourth gear. Because of the nearly identifical acceleration levels in the higher gears and the higher inertia losses in the lower gears, this shift pattern gives the best acceleration for the electric drivetrain.

Figures 50, 51 and 52 are the gradeability curves for the electric drive, diesel drive and electric/diesel combined drive, respectively, for the preliminary NTHV. Gradeability is a measure of the maximum percent grade that the vehicle can climb at a given speed in a given gear. The shapes of these curves are quite similar to the acceleration curves. Since they are steady state conditions, the inertial losses have not been included in these plots. As a result, for the electric drive (Figure 50) there is even less difference between the gradeability curves in the different gears than there is in the acceleration curves. The minimum specified gradeabilities for this program[12] are about equal to the maximum gradeability of the electric drive, and well below those of the diesel and the combined electric/diesel drives.

The electric ranges of the different NTHV system packages are shown in Figure 7 (Section 4). The electric range of the baseline NTHV using only its battery energy over the standard driving cycles is

Driving Cycle	Electric Range
Federal Urban Driving Cycle	25.5 km
Federal Highway Driving Cycle	29.0 km
SAE J227a(B) Cycle	40.2 km

The fuel consumption of the diesel engine when driving over these same cycles is

Driving Cycle	Electric Range
Federal Urban Driving Cycle	14.14 km/ℓ
Federal Highway Driving Cycle	19.34 km/ℓ
SAE J227a(B) Cycle	12.39 km/ℓ

The fuel consumption in diesel drive is high in the J227a(B) cycle primarily because of the relatively large amount of idle time in that cycle. By comparison, the electric range is much greater because the electric drain at idle is zero.

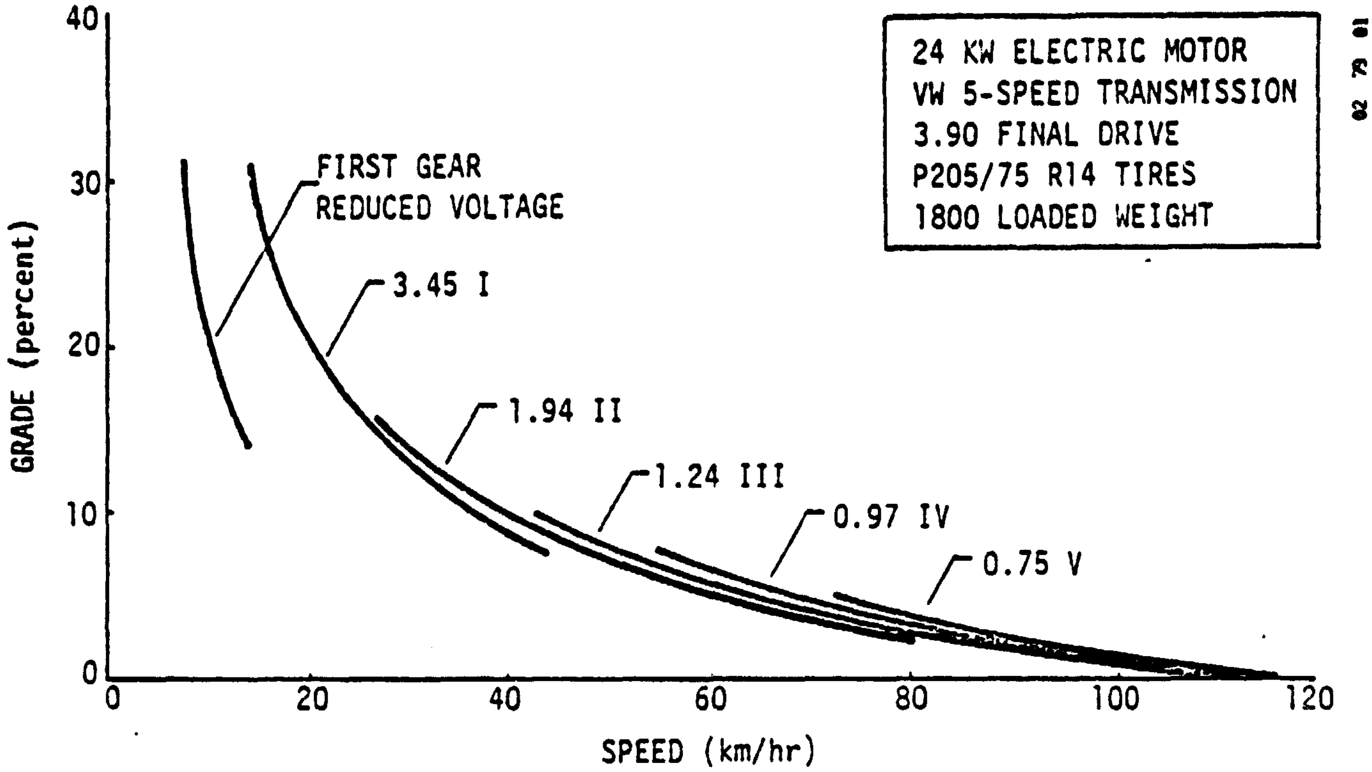

Figure 50. Gradeability Curves (Electric Drive)

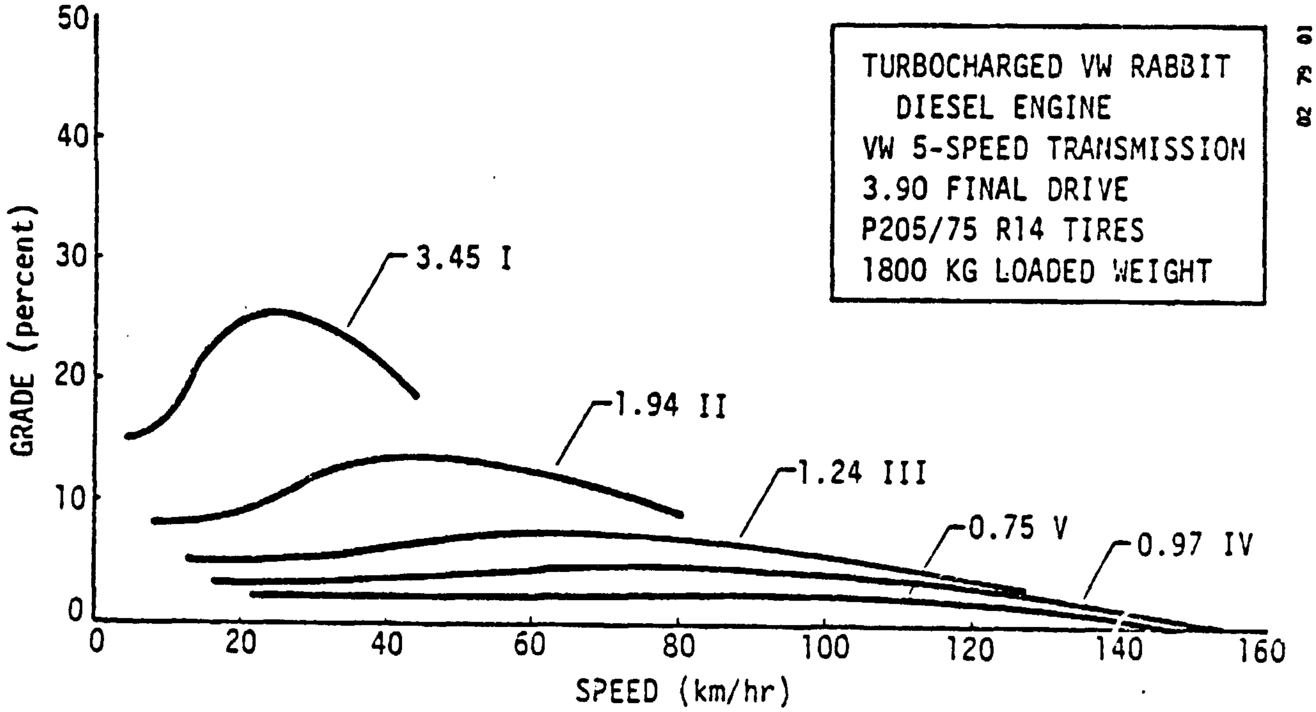

Figure 51. Gradeability Curves (Diesel Drive)

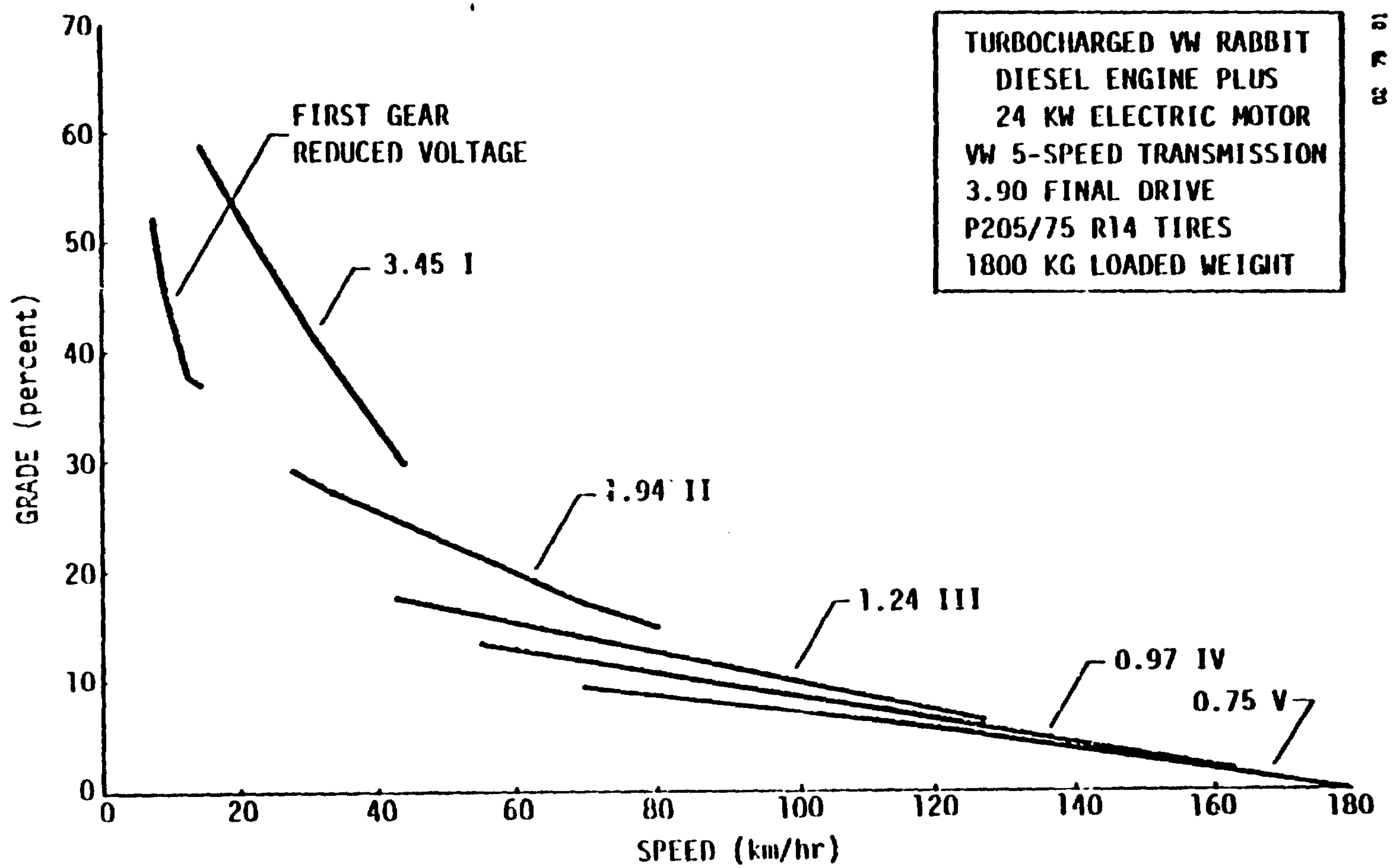

Figure 52. Gradeability Curves (Combined Electric and Diesel Drives)

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The acceleration and gradeability of the NTHV packages always gave better results than the minimum specified requirements for this program. The electric range of a NTHV depends greatly on the system package, the operational strategy, and the mission through which the vehicle is being taken.

SECTION 16

MISSION EFFECTS

As mentioned above, because the NTHV is intended to replace an all-purpose ICE vehicle, all of The Trade-Off Studies were performed by taking the NTHV system packages through Mission A, which covers 98.8 percent of all trips. Using the hybrid vehicle in a more specific mission, such as Mission C (family and civic business), which covers 40.3 percent of all travel, increases the petroleum economy. This is shown in Table 46.

For restricted missions, the hybrid loses the advantage of being an all-purpose vehicle, and its benefit (petroleum savings) drops from \$3101 (1978\$) in Mission A to \$1097 (1978\$) in Mission C. The effects of different missions on life cycle costs have been analyzed in the Sensitivity Analysis (Task 4 of the NTHV program) and are reported in the Sensitivity Analysis Report[29].

Table 46. Effects of Taking the Baseline NTHV Through Different Missions

Mission	Trip Purpose	Fraction of Trips	Annual Travel (km)	Annual Fuel Consumption (ℓ)	Fuel Economies (km/ℓ)	Annual Electricity Consumption (kW-hr)	Electricity Economy (km/kW-hr)	Electric Range (km)
A	Commuters Family Business Civic Social and Recreational	98.8	18,596	540	34.42	3225	5.77	35.9
C	Family and Civic Business	40.3	4,635	48	97.19	1387	3.35	35.2

SECTION 17

DETERMINE FLEET PETROLEUM CONSUMPTION

There are several econometric studies[30-35] that project the size and mix of automobile fleets based on consumer demand in the near term. Most of these studies concentrate on new-car demand, interactions among variables (such as purchase price, fuel economy, fuel price, economic forecast, etc.), and sensitive parameters that determine the overall fleet behavior. To include the hybrid vehicle in forecasts of the near term new car market shares would require a new dimension in automobile market projection methodology. In this study, instead of constructing a market share model for the hybrid vehicles, we tried to emphasize the impact of the hybrids on the near term fleet petroleum savings. Tables 47 and 48 show the new car fleet mixes (taken from Reference 12) for 1976 and 1985. For the 1985 mix given in Table 48, the annual fleet petroleum consumption is calculated to be 219 x 10^9 liters (58 x 10^9 gallons).

Table 47. 1976 New Car Fleet Mix[12]

Market Class	New Car Fleet Mix (%)	Fuel Economy [km/ℓ (mpg)]
Small	7.9	12.3 (29.1)
Subcompact	6.0	10.8 (25.4)
Compact	27.1	8.9 (21.0)
Full Size	37.4	6.8 (16.0)
Large	21.6	6.0 (14.1)

Table 48. 1985 New Car Fleet Mix[12]

Market Class	New Car Fleet Mix (%)	Fuel Economy [km/ℓ (mpg)]
Small	11	17.6 (41.5)
Subcompact	14	16.1 (38.0)
Compact	30	13.5 (32.0)
Full-Size	30	10.6 (25.0)
Large	15	8.9 (21.0)

An NTHV market share on the order of 100,000 vehicles in the compact class in 1985 would save 68 x 10^6 liters (18 x 10^6 gallons) of petroleum. Moreover, if all of the 3 x 10^6 new cars in the compact class were replaced by NTHVs, the fleet petroleum savings would be 2040 x 10^6 liters (540 x 10^6 gallons), or 0.931 percent.

Our present life cycle cost analysis has shown that the purchase price of a hybrid vehicle ($8,518.72 in 1978$ for the baseline NTHV) is higher than the reference ICE vehicle ($6,631.44 in 1978$). As the battery capacity and therefore the electric range of the hybrid vehicle increases, the petroleum savings increase, but so also does the purchase price and the life cycle cost of the vehicle.

The market share for the hybrid vehicle can be studied by just considering the hybrid vehicle demand elasticity with respect to purchase price as -1.2 (Reference 30). This elasticity value implies that a one percent increase in purchase price will result in a 1.2 percent decrease in demand for hybrid vehicles.

The penetration of difference NTHV system packages into the compact class market in 1985 was investigated by using a simple constant price elasticity scenario. The result of this scenario is shown in Table 49. A hybrid vehicle with a 60V battery and a 28 km electric range seems to have the maximum potential for petroleum savings.

However, the potential economic value of the hybrid vehicle would be higher to a producer subject to mandatory petroleum economy regulations and to a government which is attempting to minimize foreign petroleum dependence. The purchase prices in Table 49 will vary significantly for various pricing policy decisions. Thus higher manufacturing cost of hybrid vehicles does not necessarily imply a proportionately higher purchase price. This trend will push the hybrid vehicles to higher battery capacity and, as a result, to longer electric range.

Table 49. Price Elasticity Scenario for the Near Term Hybrid Vehicles

Battery Capacity (v)	Purchase Price (1978$)	Decrease in NTHV Demand (%)	NTHVs Purchased	Annual Compact Class Fuel Consumption ($\times 10^6 \ell$)
--	6,631.44	--	0	4200
36	7,468.40	15.51	2,545,500	2520
48	7,762.68	20.47	2,385,885	2439
60	8,105.84	26.68	2,199,595	2427
72	8,518.72	34.15	1,975,455	2501
84	8,799.96	39.24	1,822,779	2510
90	8,925.24	41.51	1,754,768	2529
96	9,019.48	43.21	1,703,700	2535

SECTION 18

TRADE-OFF RESULTS

The present trade-off studies show that a near term hybrid vehicle that can perform as well as the reference ICE vehicle can be designed and built. This all-purpose passenger vehicle, when taken through Mission A with its accessories on, can save as much as 60 percent of the petroleum which the ICE vehicle consumes, but at a 33 percent higher life cycle cost. In the near term, the NTHV can be cost competitive with the reference ICE vehicle when the price of petroleum rises to 0.50 $/liter or when the cycle life of the batteries increase to 3650.

The NTHV configuration outlined below is a result of the present trade-off studies. In order to be certain that the NTHV will exhibit the greatest potential for petroleum savings in the near term, we evaluated both the marketability (including customer acceptance and cost/benefits) and the manufacturability and design (including mass production, packaging and performance) of every subsystem and component.

18.1 VEHICLE SIZE AND WEIGHT

The 1980 General Motors X-body represents the state of the art in packaging and weight reduction for a five-passenger vehicle and is a very good base upon which to build a near term hybrid. The initial size estimates of the hybrid vehicle are given in Table 50.

The curb weight of the hybrid vehicle is estimated at 1754 kg. The initial weight estimates of the vehicle's subsystems and components are given in Table 51.

18.2 POWER CONFIGURATION

The parallel hybrid concept has been chosen because its overall efficiency is the highest of the feasible alternatives and because it allows the ratio of heat engine to electric motor power to be varied (for optimized operation).

18.3 POWER SIZING - HEAT ENGINE/ELECTRIC MOTOR/BATTERY CAPACITY

The choice of battery capacities was narrowed to 10.5 to 14.7 kW-hr by the benefit-cost behavior of the hybrid system packages, by

Table 50. Initial Size Estimates of the NTHV

Wheelbase	265 cm
Length	449 or 500 cm
Height	139 cm
Width	173 cm
Front Tread	149 cm
Rear Tread	145 cm
Front Seat Headroom	97 cm
Front Seat Leg Room	107 cm
Front Seat Shoulder Room	143 cm
Front Seat Hip Room	140 cm

Table 51. Initial Weight Estimates of the NTHV

Subsystems and Components	Weight (kg)	% of Total
Frame and Body Structure	307.0	17.50
Removable Panels	124.6	7.10
Basic Body	170.0	9.69
Suspension System	80.0	4.56
Brake System	91.0	5.19
Steering System	27.3	1.56
Tires	65.0	3.71
Wheels	47.0	2.68
Restraints	14.2	0.81
Air Conditioning	22.3	1.27
Transmission	54.5	3.11
Drive System	64.0	3.65
Heat Engine	136.0	7.75
Motor	70.0	3.99
Controller	5.0	0.29
Charger	5.0	0.29
Batteries	392.0	22.35
Power Harness	22.7	1.29
Battery Tray	39.7	2.26
Microprocessor with Sensors	17.0	0.97
Total Curb Weight	1754.3	100.00

the reflections of those packages on the marketability scenarios, and by the packaging restrictions. With the inclusion of the accessories, the choice becomes 14.7 kW-hr (that is, an 84 Volt battery pack). The optimum electric motor/heat engine power combination for an 84 Volt battery is a 29 kW (peak power) electric motor and a 48.5 kW (peak power) heat engine.

18.4 HEAT ENGINE SELECTION

Of the four most likely heat engine candidates, (spark ignition, stratified charge spark ignition, naturally aspirated diesel and turbocharged diesel) we verified that the lightweight turbocharged diesel offers the greatest potential in fuel savings.

18.5 ELECTRIC MOTOR SELECTION

The three dc motors considered in the trade-off studies show similar performance and cost properties. However, the dc compound motor was chosen for the NTHV because it requires a less complex control system design.

18.6 TRANSMISSION TYPE

The computer controlled manual transmission maximizes the petroleum savings in an NTHV, but its availability in the near term and its public acceptance are questionable. Therefore, our choice is the computer controlled automatic transmission.

18.7 BATTERY TYPE

As the present study shows, an NTHV needs batteries that last throughout the life of the vehicle in order to be cost competitive to the reference ICE vehicle. The nickel-iron battery is then the best choice if it becomes available in the near term. Otherwise, the best alternative is the ISOA lead-acid battery.

18.8 REGENERATIVE BRAKING

The advantages (including cost effectiveness) of regenerative braking have been shown in previous studies and confirmed in this study. So the NTHV will have regenerative braking.

18.9 HEATING

The NTHV will have a separate petroleum-burning heater. Such a heater is more fuel efficient and cost effective than running the heat engine for heating purposes.

18.10 OPERATIONAL STRATEGY

For a warm start, the batteries will initially be depleted to their maximum allowable state of discharge, after which the heat engine will become the primary drive component. For a cold start and for a self-contained warmup, the heat engine will be the primary drive component until the batteries reach their minimum allowable operating temperature. Then the warm start operational strategy will be used.

A summary of the near term hybrid vehicle specifications is given in Table 52.

Figure 53 shows one of the preliminary 84 Volt battery packaging configurations, and a possible battery ventilation system is illustrated in Figure 54 for a different battery configuration. The performance specifications of the 85 Volt NTHV are given in Table 53, and its life cycle costs in Table 54.

Table 52. Summary of the NTHV Specifications

Weight	
Curb Weight	1754 kg
Inertia Weight	1894 kg
Dimensions	
Length	449 or 500 cm
Width	173 cm
Height	139 cm
Wheelbase	265 cm
Battery	
Type	ISOA Lead/Acid
Capacity (3 hr rate)	14.7 kW-hr
Voltage	84V
Weight	392 kg
Size	181 DM^3
Heat Engine	
Type	4-cylinder Turbocharged VW diesel
Displacement	1475 cc
Power	48.5 kW @ 5000 rpm
Torque	119 Nm @ 1000 rpm
Speed	5000 rpm
Electric Motor	
Type	Compound wound dc
Power Rating	29 kW intermittent; 15 kW continuous
Field Control	Transistor, 3:1 speed range
Maximum Speed	10,000 rpm
Transaxle	
Type	3-speed, computer controlled automatic with lockup torque converter
Number of Gears	3
Gear Ratios - 1	2.84:1
2	1.60:1
3	1.00:1
Final Drive Ratio	2.53:1

Table 52 (Cont'd)

<u>Brakes</u>	
Type	Disc/drum with regenerative braking
<u>Suspension</u>	
Type	Four-wheel independent
<u>Steering</u>	
Type	Powered rack and pinion
<u>Tires</u>	
Type	Radial ply P205/75 R14
<u>Microprocessor</u>	
Type	8-bit single chip with associated memory and control circuits

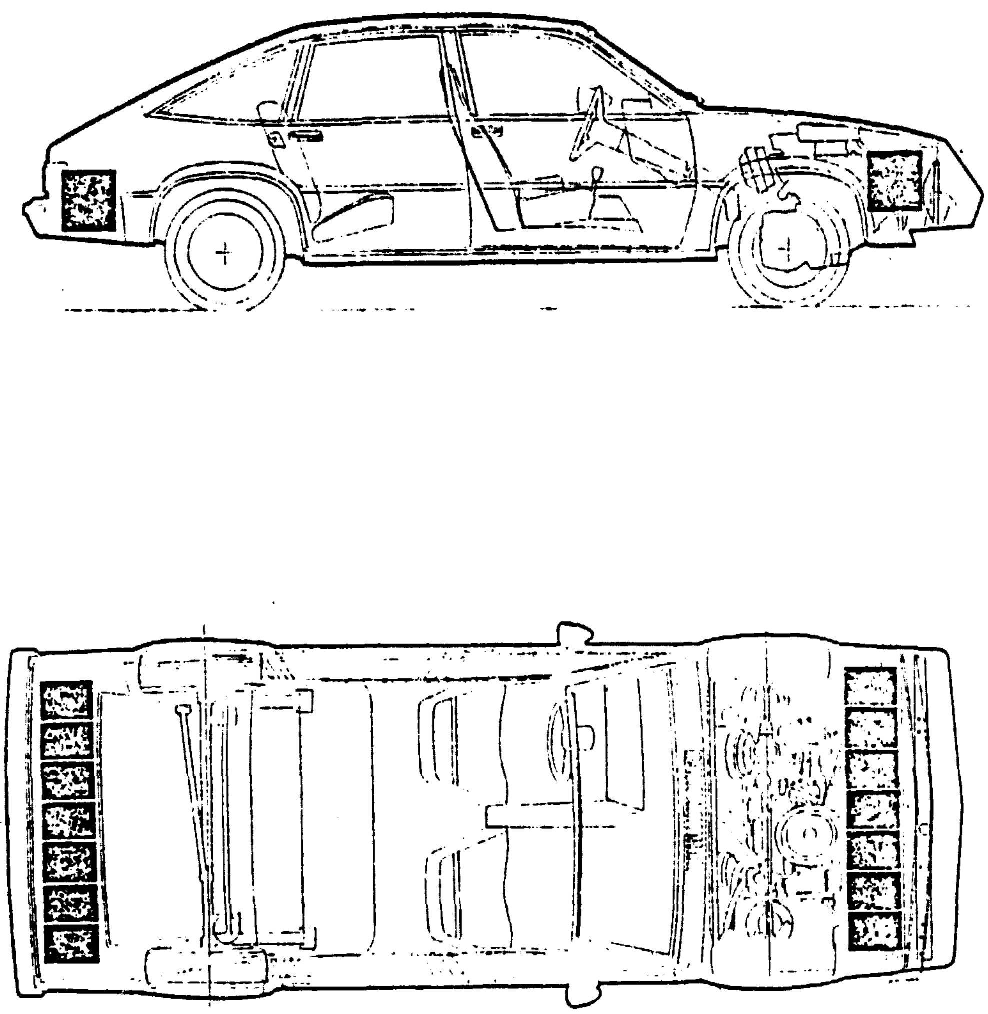

Figure 53. Possible Battery Configuration in an X-Body

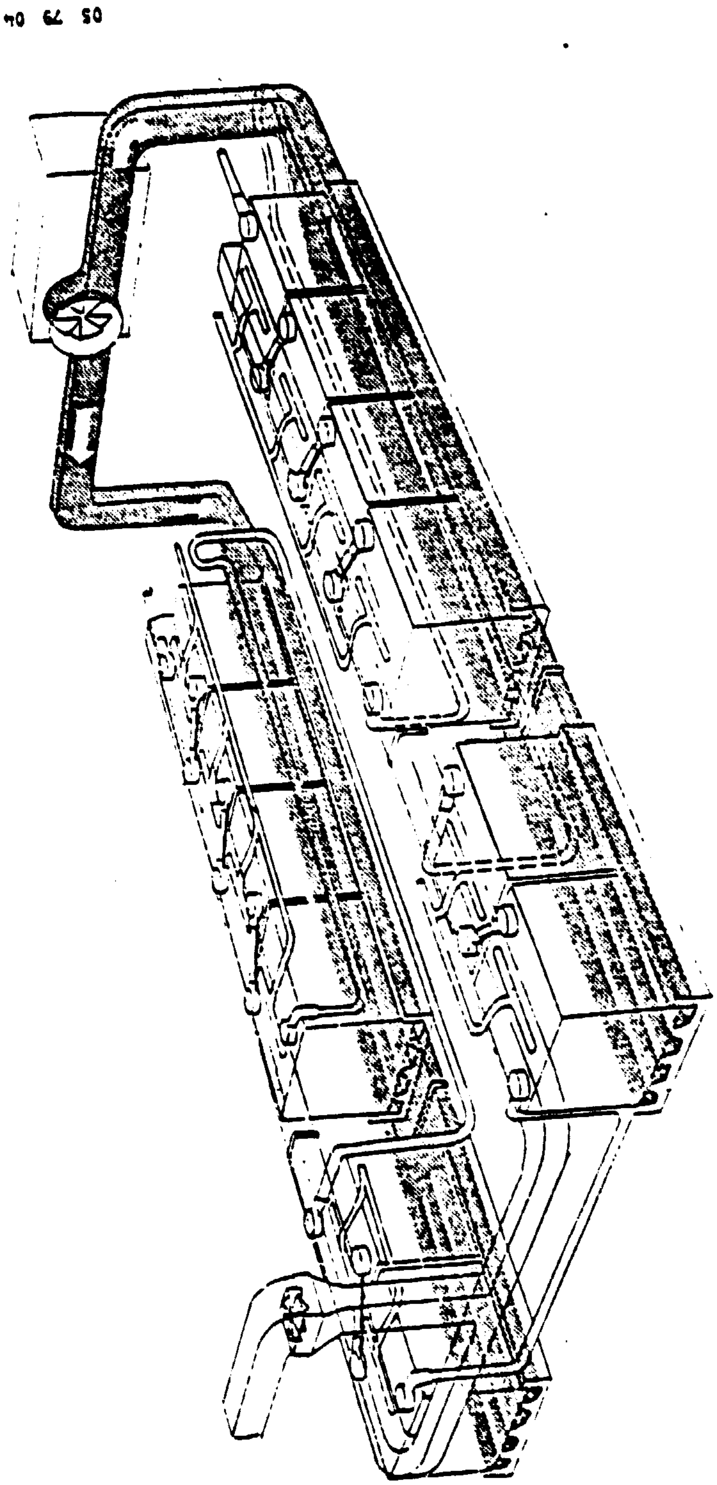

Figure 54. Possible Battery Ventilation System

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Table 53. Vehicle Performance Specifications*

P1	Minimum Non-Refueled Range		
	P1.1	FUDC	680km
	P1.2	FUDC	498km
	P1.3	J227a(B)	437km
P2	Cruise Speed		88km/h
P3	Maximum Speed		
	P3.1	Maximum speed	180 km/h
	P3.2	Length of time maximum speed can be maintained on level road	5 min
P4	Accelerations		
	P4.1	0.50 km/h (0.30 mph)	5 sec
	P4.2	0-90 km/h (0-56 mph)	13 sec
	P4.3	40-90 km/h (25-56 mph)	10 sec

P5 Gradeability (Heat Engine only)**

		Grade	Speed
P5.1		3%	118 km/hr
P5.2		5%	86 km/hr
P5.3		8%	80 km/hr
P5.4		15%	25 km/hr
P5.5	Maximum Grade	25%	

P6	Payload Capacity		520kg
P7	Cargo Capacity		$0.5m^3$
P8	Consumer Costs		
	P8.1	Consumer purchase price (1978 $)	9005$
	P8.2	Consumer life cycle cost (1978 $)	0.14$/km

*84V Near Term Hybrid Vehicle with the accessories on.

**Distance is not included, because in diesel drive the distance is limited only by the fuel tank capacity.

Table 53 (Cont'd)

P9	Emissions (Heat Engine Only)	
	P9.1 Hydrocarbons (HC)	0.18 gm/km
	P9.2 Carbon monoxide (CO)	0.55 gm/km
	P9.3 Nitrogen oxides (NO_x)	1.01 gm/km
P10	Ambient Temperature Capability	
	Temperature range over which minimum performance requirements can be met	-20°C to +40°C
P11	Rechargeability	
	Maximum time to recharge from 80% depth-of-discharge	6-8 hrs
P12	Required Maintenance	
	Routine maintenance required per month	1 hr
P13	Unserviced Storeability	
	Unserviced storage over ambient temperature range of -30°C to +50°C (-22°F to +122°F)	
	P13.1 Duration	120 day
	P13.2 Warm-up required	1-2 min
P14	Reliability	
	P14.1 Mean usage between failures - powertrain	40,000 km
	P14.2 Mean usage between failures - brakes	40,000 km
	P14.3 Mean usage between failures - vehicle	40,000 km
P15	Maintainability	
	P15.1 Time to repair - mean	5.0 hrs
	P15.2 Time to repair - variance	2.0 hrs
P16	Availability	
	Minimum expected utilization rate (i.e., 100 x time in service ÷ (time in service + time under repair)	97%
P17	Additional Accessories and Amenities	List
	Fuel-burning heater, air conditioner, cooling fan, alternator, air pump	

Table 54. Life Cycle Costs of the 84V Near Term Hybrid Vehicle

JPL NEAR TERM HYBRID PASSENGER VEHICLE DEVELOPMENT PROGRAM-PHASE I MAY 1979

PRESENT VALUE OF TOTAL LIFE CYCLE COSTS — RUN NO. 26

(1978 $) — DATE MAY 21 1979

DISCOUNT RATE= 2.00 % — SYSTEM PACKAGE NO. 9

	$/KM	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	TOTAL $	% OF LCC
ACQUISITION COSTS														
PURCHASE PRICE	0.04571	2207.2	2163.9	2121.3	2079.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8572.6	32.38
SALES TAXES	0.00235	441.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	441.4	1.67
INTEREST	0.01449	699.6	685.8	672.4	659.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2717.0	10.26
SALVAGE VALUE OF VEHICLE	0.00193	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-362.1	-362.1	1.37
TOTAL ACQUISITION COST	0.06062	3348.2	2849.8	2793.9	2739.1	0.0	0.0	0.0	0.0	0.0	0.0	-362.1	11368.9	42.95
OPERATING COSTS														
ENERGY COSTS														
DIESEL FUEL	0.00884	251.8	213.1	190.8	175.1	163.5	152.7	141.4	131.0	122.8	115.7	0.0	1657.6	6.26
ELECTRICITY	0.00902	267.7	223.1	196.9	178.2	164.0	151.4	140.5	130.9	122.9	116.5	0.0	1692.1	6.39
TOTAL ENERGY COST	0.01786	519.6	436.1	387.6	353.3	327.5	304.1	281.8	262.0	245.7	232.2	0.0	3349.7	12.65
MAINTENANCE + REPAIR COSTS														
PROPULSION SYSTEM MAINT	0.00448	57.6	148.4	43.3	124.7	100.4	57.4	92.8	169.5	24.6	20.7	0.0	839.6	3.17
REPAIRS	0.00701	218.9	179.8	156.5	139.7	126.9	115.6	105.8	97.3	90.2	84.4	0.0	1315.1	4.97
TOTAL MAINT + REPAIR COST	0.01149	276.6	328.2	200.0	264.4	227.2	172.9	198.6	266.8	114.8	105.1	0.0	2154.7	8.14
BATTERY REPLACEMENT COSTS														
BATTERY PURCHASE PRICE	0.01971	0.0	0.0	159.4	625.1	561.8	350.5	589.1	336.9	519.0	555.1	0.0	3696.9	13.97
SALES TAXES	0.00104	0.0	0.0	69.1	0.0	0.0	65.1	0.0	0.0	61.3	0.0	0.0	195.5	0.74
INTEREST	0.00383	0.0	0.0	31.0	121.4	109.1	68.1	114.4	65.4	100.8	107.8	0.0	717.9	4.71
SALVAGE VALUE	0.00208	0.0	0.0	-138.2	0.0	0.0	-130.2	0.0	0.0	-122.7	0.0	0.0	-391.0	1.48
TOTAL BATTERY REPL COST	0.02250	0.0	0.0	121.3	746.5	670.9	353.5	703.3	402.3	558.5	662.9	0.0	4219.2	15.94
OTHER OPERATING COSTS														
TIRE REPL EVERY 50000 KM	0.00209	65.4	53.7	40.7	41.7	37.9	34.5	31.6	29.1	26.9	25.2	0.0	392.8	1.48
INSURANCE	0.00902	281.5	231.2	201.2	179.6	163.1	148.6	136.0	125.1	116.0	108.5	0.0	1690.8	6.39
ANNUAL REG. AND LICENSE	0.00164	51.2	42.0	36.6	32.7	29.7	27.0	24.7	22.8	21.1	19.7	0.0	307.4	1.16
ACCESSORIES	0.00173	54.0	44.4	38.6	34.5	31.3	28.5	26.1	24.0	22.2	20.8	0.0	324.5	1.23
GARAGING,PARKING,TOLLS	0.01384	432.2	355.0	309.0	275.8	250.4	228.1	208.8	192.1	178.1	166.6	0.0	2596.0	9.81
TOTAL OTHER OPERATING COST	0.02832	884.2	726.4	632.1	564.3	512.4	466.7	427.2	393.1	364.3	340.9	0.0	5311.6	20.07
TOTAL OPERATING COST	0.08017	1680.4	1490.8	1341.1	1928.5	1737.8	1297.2	1611.1	1324.2	1283.3	1340.9	0.0	15035.3	56.80
R+D COST AMORT (500000 VEH)	0.00036	67.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	67.7	0.26
PRESENT VALUE OF TOTAL LCC	0.14115	5096.2	4340.6	4135.0	4667.6	1737.8	1297.2	1611.1	1324.2	1283.3	1340.9	-362.1	26471.8	100.00

BENEFIT PER HTHV = 4378.51 - 1657.61 = 2720.90

COST OF ACCRUING THIS BENEFIT PER HTHV = (26471.82 - 1657.61) - (19927.82 - 4378.51) = 9264.91

NET BENEFIT PER HTHV = -6544.00

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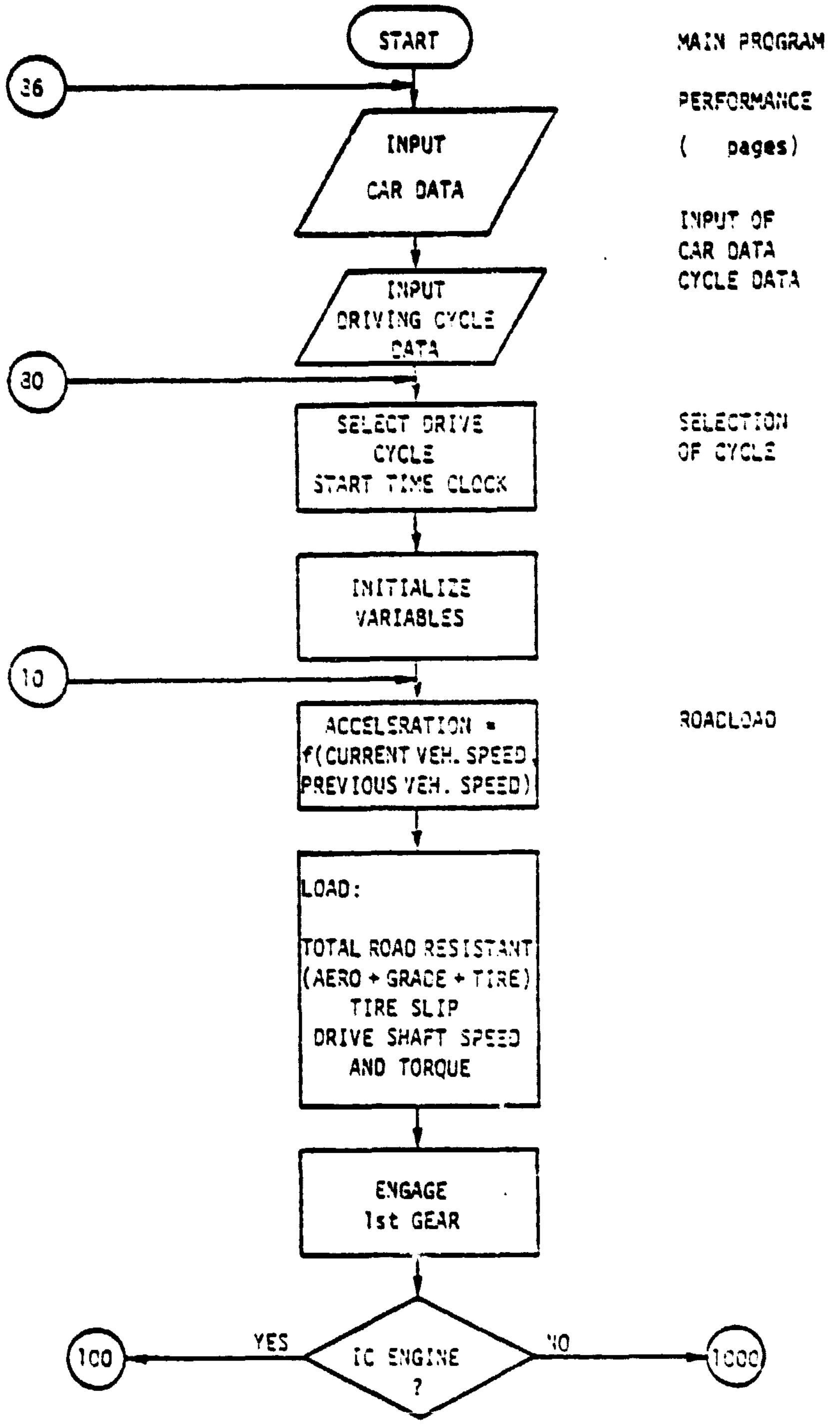
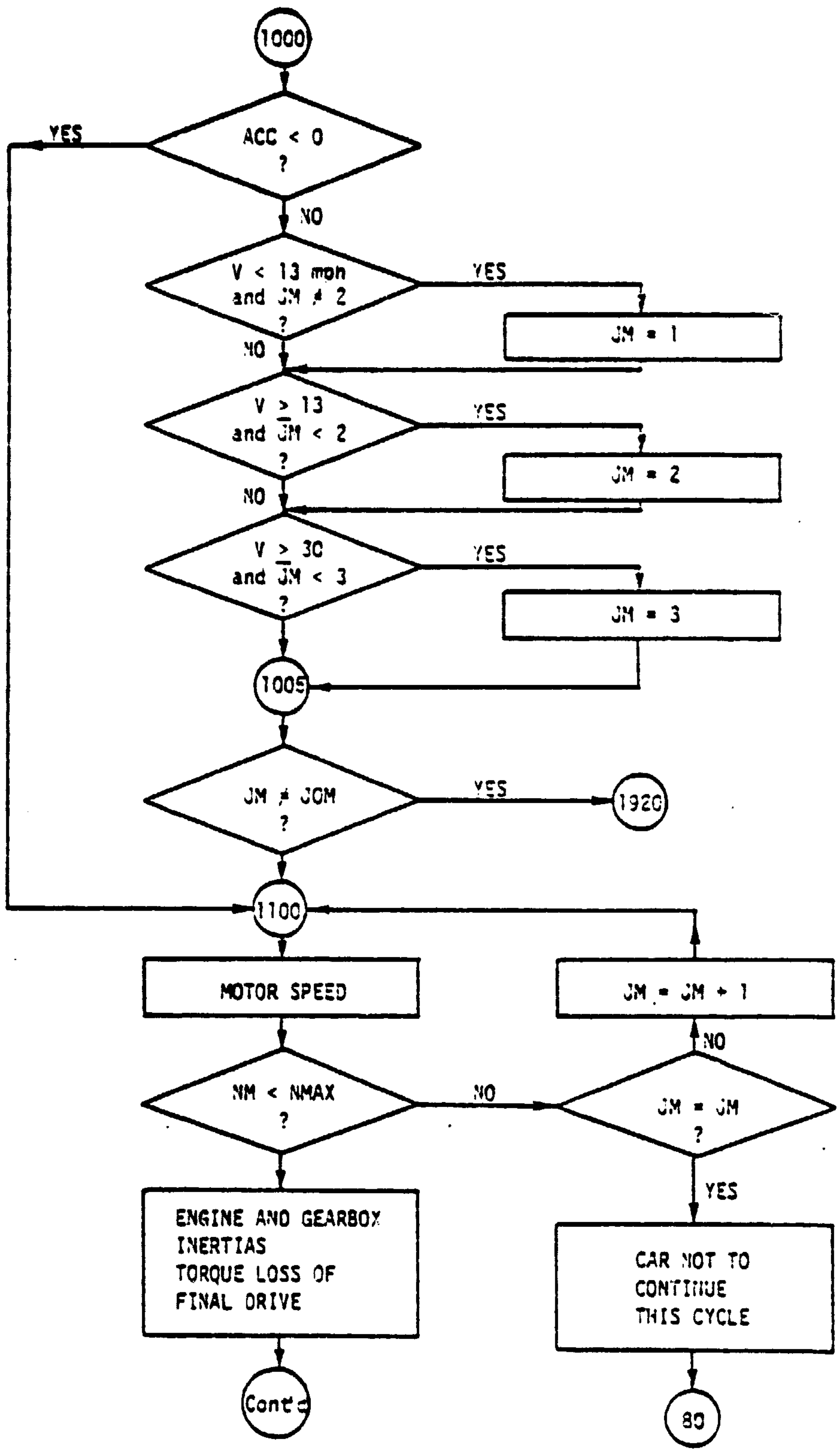
APPENDIX A

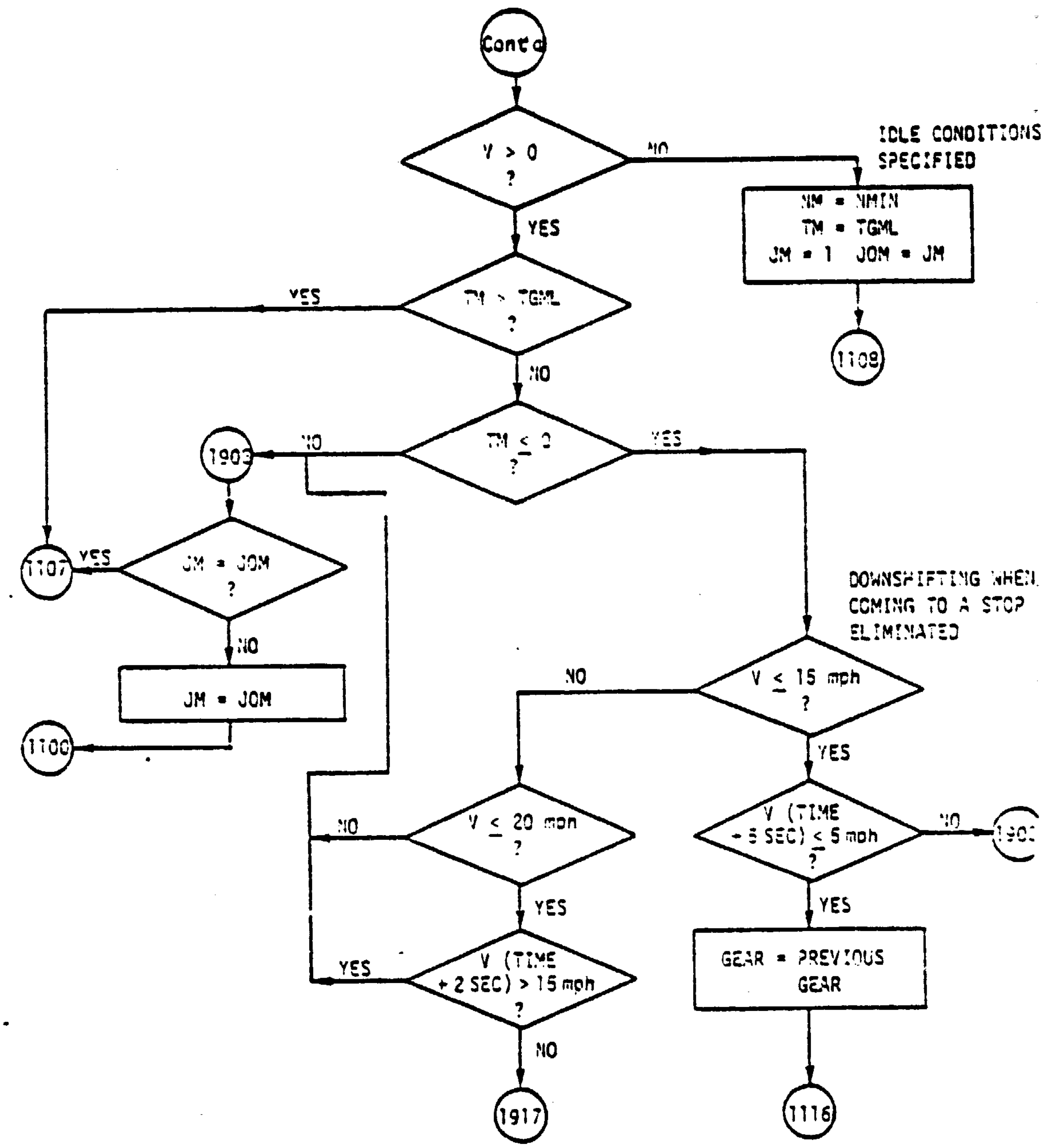
MINICARS' VEHICLE PERFORMANCE SIMULATION PROGRAM, CARSIM

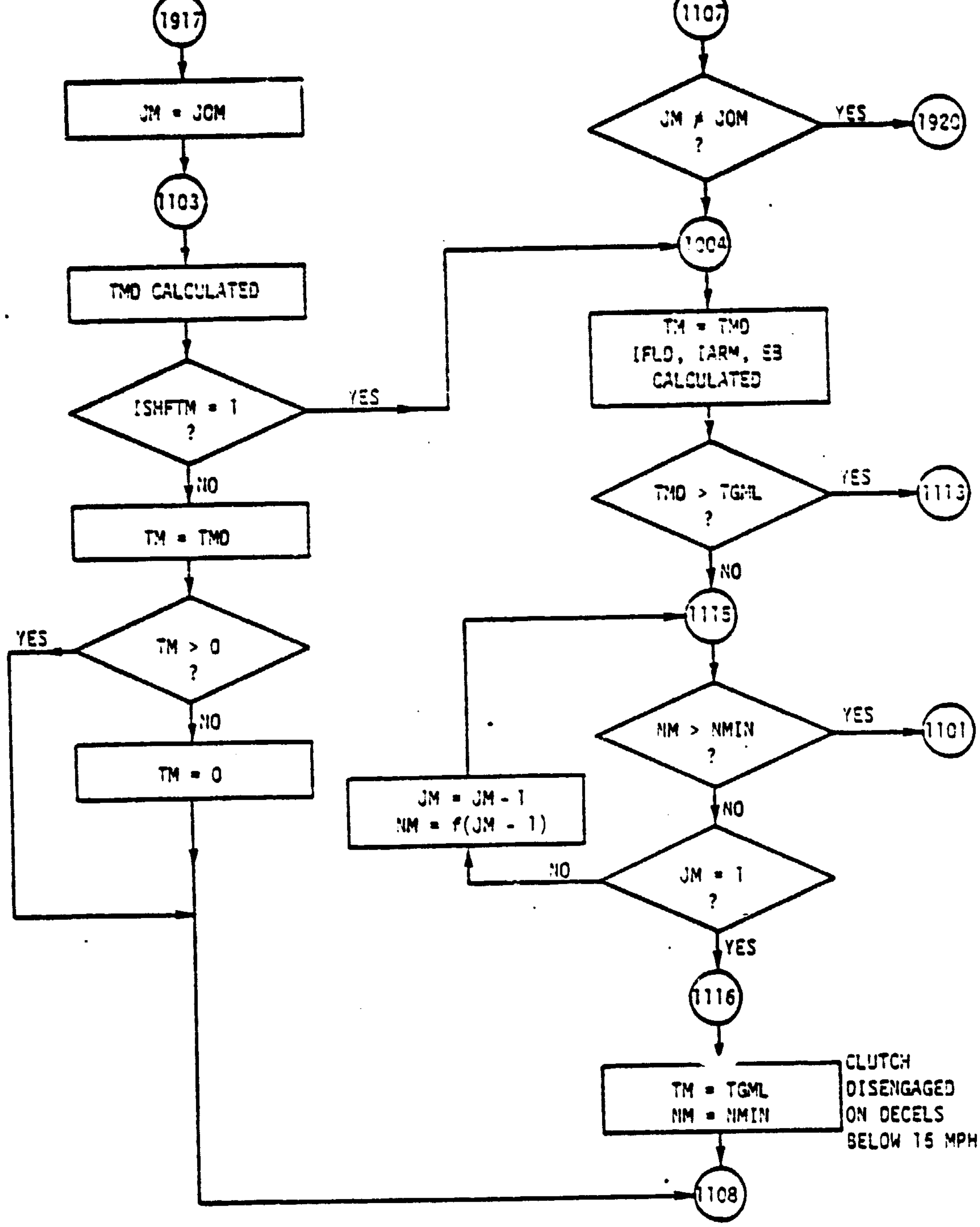
APPENDIX A
CARSIM

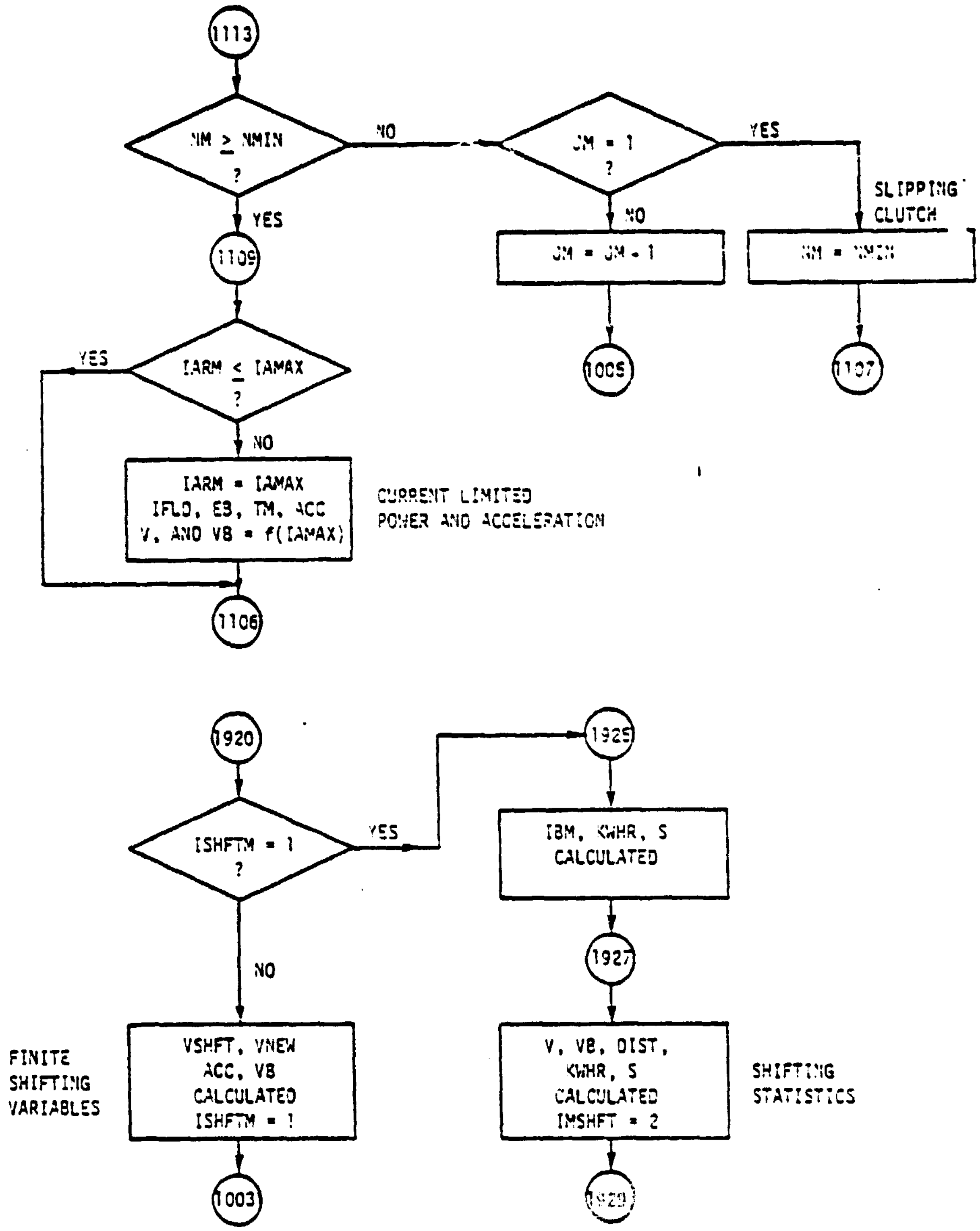
Minicars' vehicle performance simulation program, CARSIM, was modified to include the electrical components of a hybrid vehicle. The following detailed flow diagram represents a vehicle powered by either an internal combustion engine or an electric motor, or both.

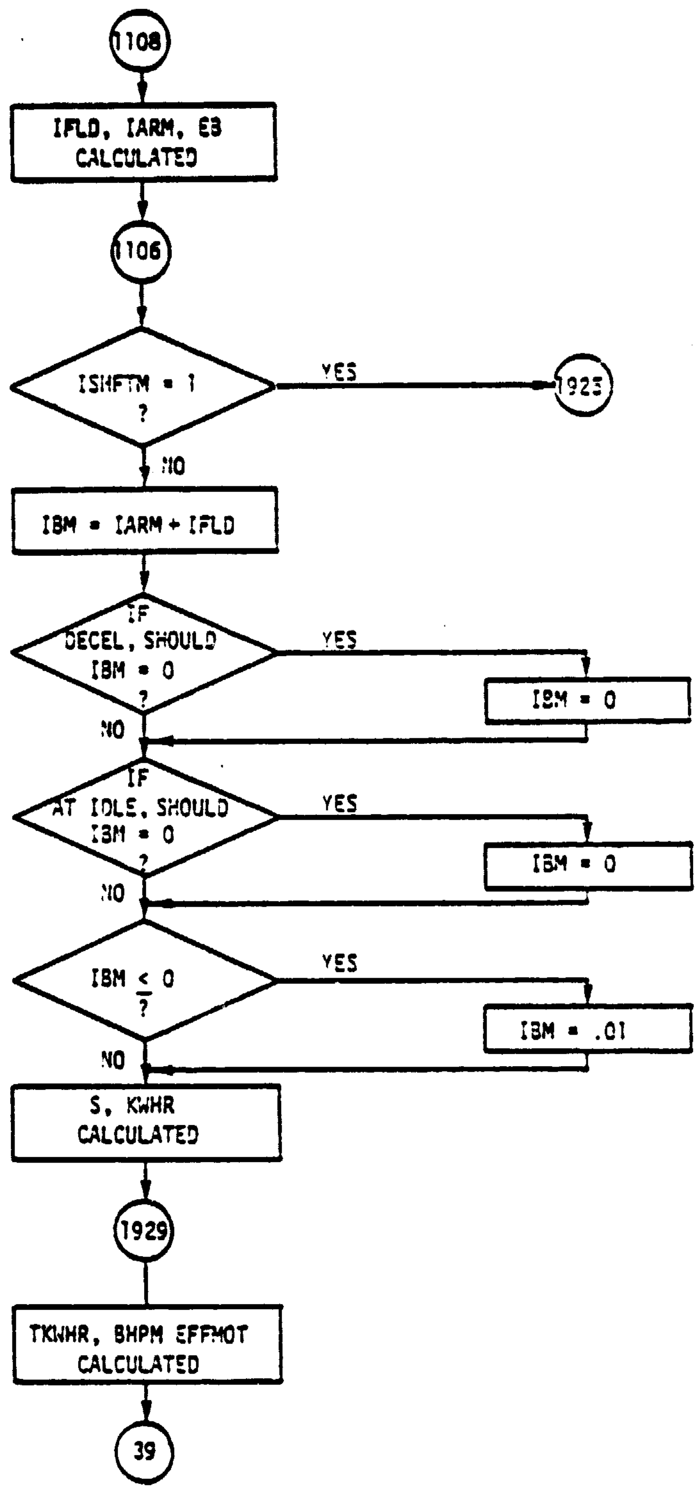

START
MAIN PROGRAM
PERFORMANCE
(pages)
36
INPUT
CAR DATA
INPUT OF
CAR DATA
CYCLE DATA
INPUT
DRIVING CYCLE
DATA
30
SELECT DRIVE
CYCLE
START TIME CLOCK
SELECTION
OF CYCLE
INITIALIZE
VARIABLES
10
ACCELERATION =
f(CURRENT VEH. SPEED,
PREVIOUS VEH. SPEED)
ROADLOAD
LOAD:
TOTAL ROAD RESISTANT
(AERO + GRADE + TIRE)
TIRE SLIP
DRIVE SHAFT SPEED
AND TORQUE
ENGAGE
1st GEAR
100
YES
IC ENGINE
?
NO
1000

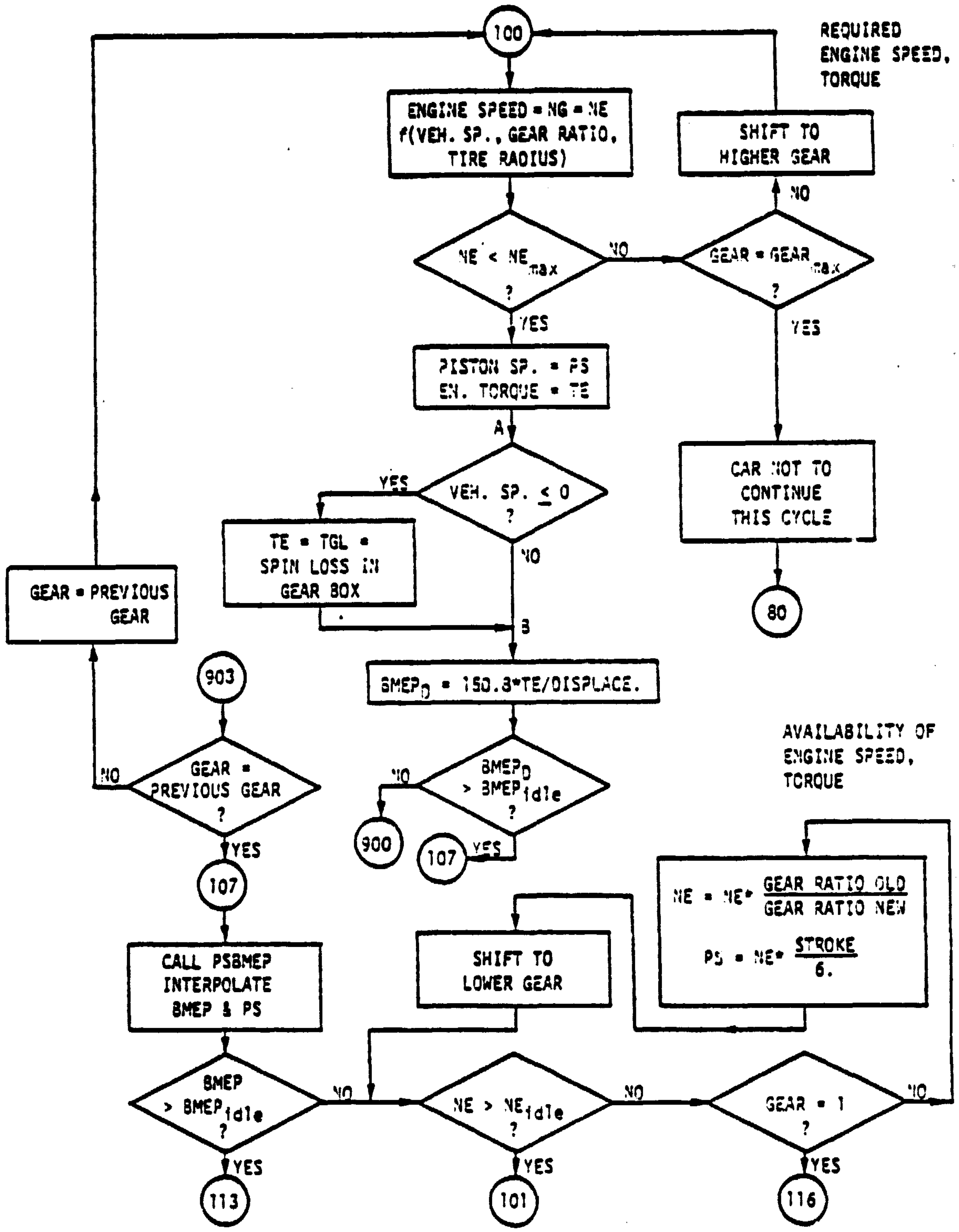

1000
ACC < 0 ?
YES
NO
V < 13 mph and JM ≠ 2 ?
YES
JM = 1
NO
V ≥ 13 and JM < 2 ?
YES
JM = 2
NO
V ≥ 30 and JM < 3 ?
YES
JM = 3
1005
JM ≠ JOM ?
YES
1920
1100
MOTOR SPEED
JM = JM + 1
NO
NM < NMAX ?
NO
JM = JM ?
YES
ENGINE AND GEARBOX INERTIAS TORQUE LOSS OF FINAL DRIVE
CAR NOT TO CONTINUE THIS CYCLE
Cont'd
80

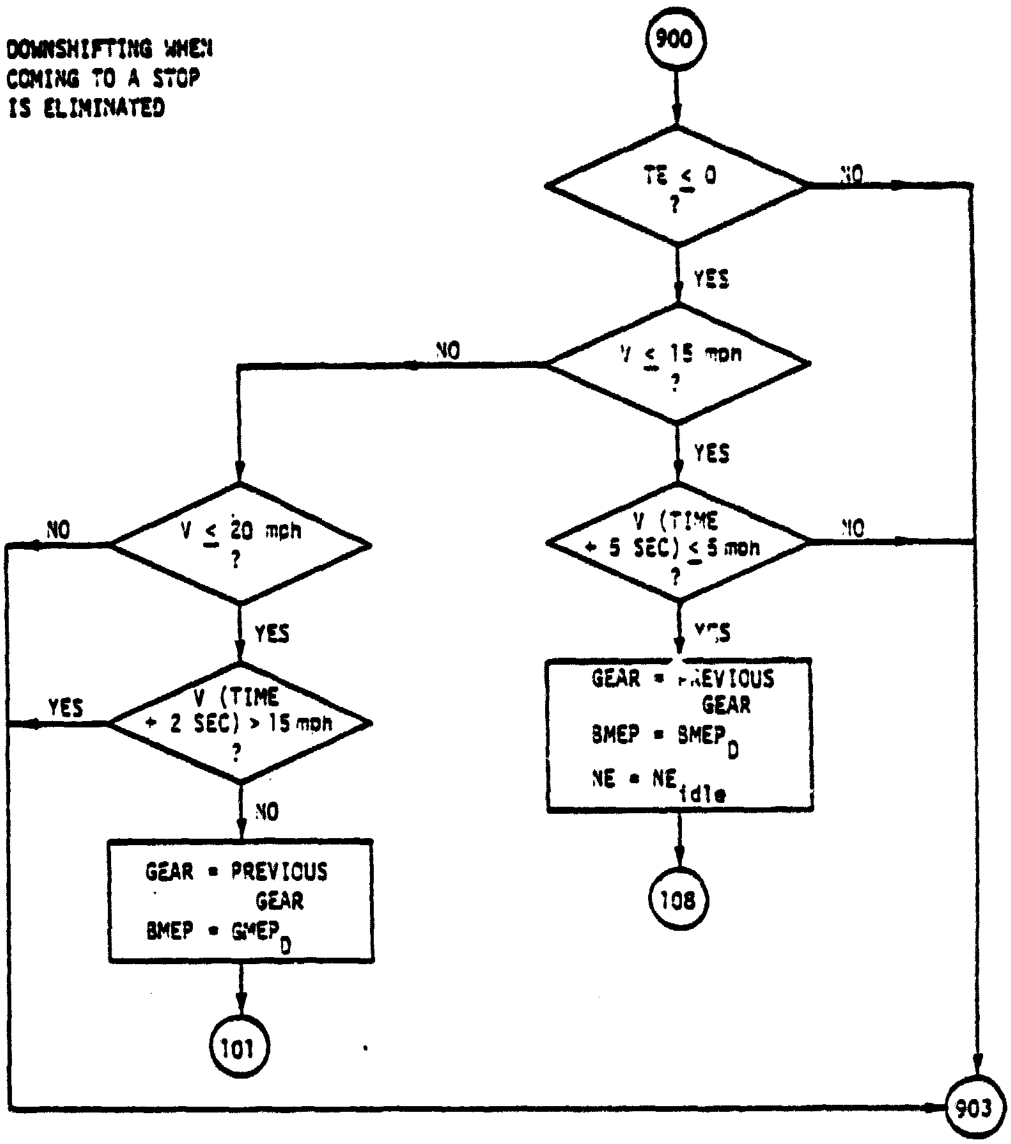

Cont'd
V > 0 ?
NO
YES
IDLE CONDITIONS SPECIFIED
NM = NMIN
TM = TGML
JM = 1 JOM = JM
1108
TM > TGML ?
YES
NO
TM ≤ 0 ?
NO
YES
1903
JM = JOM ?
YES
1107
NO
JM = JOM
1100
DOWNSHIFTING WHEN COMING TO A STOP ELIMINATED
V ≤ 15 mph ?
NO
YES
V ≤ 20 mph ?
NO
YES
V (TIME + 5 SEC) ≤ 5 mph ?
NO
YES
V (TIME + 2 SEC) > 15 mph ?
YES
NO
GEAR = PREVIOUS GEAR
1917
1116


1917
JM = JOM
1103
TMD CALCULATED
ISHFTM = 1
?
YES
NO
TM = TMD
TM > 0
?
YES
NO
TM = 0
1107
JM ≠ JOM
?
YES
1920
1004
TM = TMD
IFLD, IARM, EB
CALCULATED
TMD > TGML
?
YES
1113
NO
1115
NM > NMIN
?
YES
1101
NO
JM = JM - 1
NM = f(JM - 1)
JM = 1
?
NO
YES
1116
TM = TGML
NM = NMIN
CLUTCH
DISENGAGED
ON DECELS
BELOW 15 MPH
1108

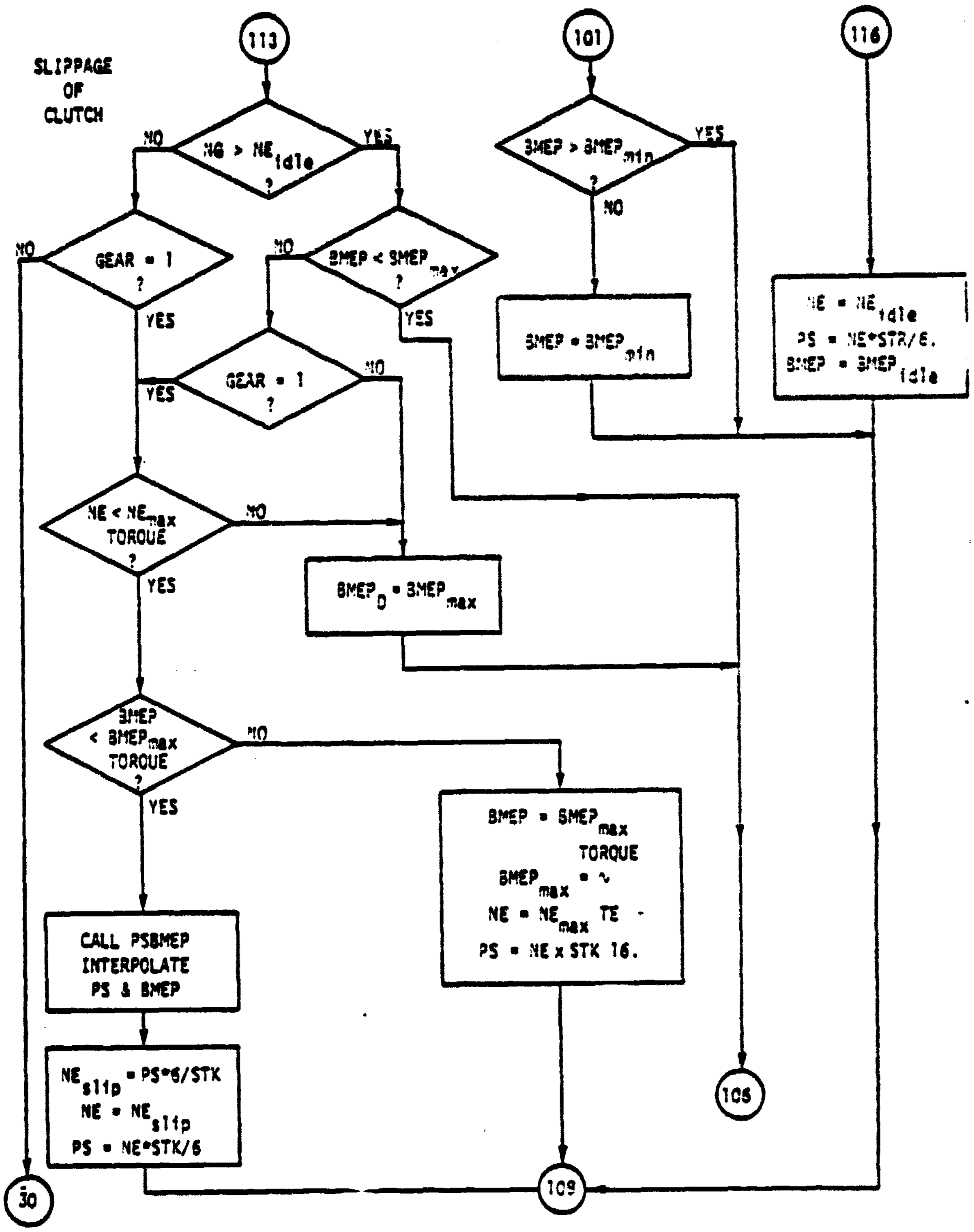

1113
NM ≥ NMIN ?
NO
YES
1109
JM = 1 ?
YES
NO
SLIPPING CLUTCH
JM = JM - 1
NM = NMIN
1005
1107
IARM ≤ IAMAX ?
YES
NO
IARM = IAMAX
IFLD, EB, TM, ACC
V, AND VB = f(IAMAX)
CURRENT LIMITED
POWER AND ACCELERATION
1106
1920
ISHFTM = 1 ?
YES
NO
1925
IBM, KWHR, S
CALCULATED
1927
FINITE
SHIFTING
VARIABLES
VSHFT, VNEW
ACC, VB
CALCULATED
ISHFTM = 1
V, VB, DIST,
KWHR, S
CALCULATED
IMSHFT = 2
SHIFTING
STATISTICS
1003
1929


1108
IFLD, IARM, EB CALCULATED
1106
ISHFTM = 1 ?
YES
1923
NO
IBM = IARM + IFLD
IF DECEL, SHOULD IBM = 0 ?
YES
IBM = 0
NO
IF AT IDLE, SHOULD IBM = 0 ?
YES
IBM = 0
NO
IBM ≤ 0 ?
YES
IBM = .01
NO
S, KWHR CALCULATED
1929
TKWHR, BHPM EFFMOT CALCULATED
39

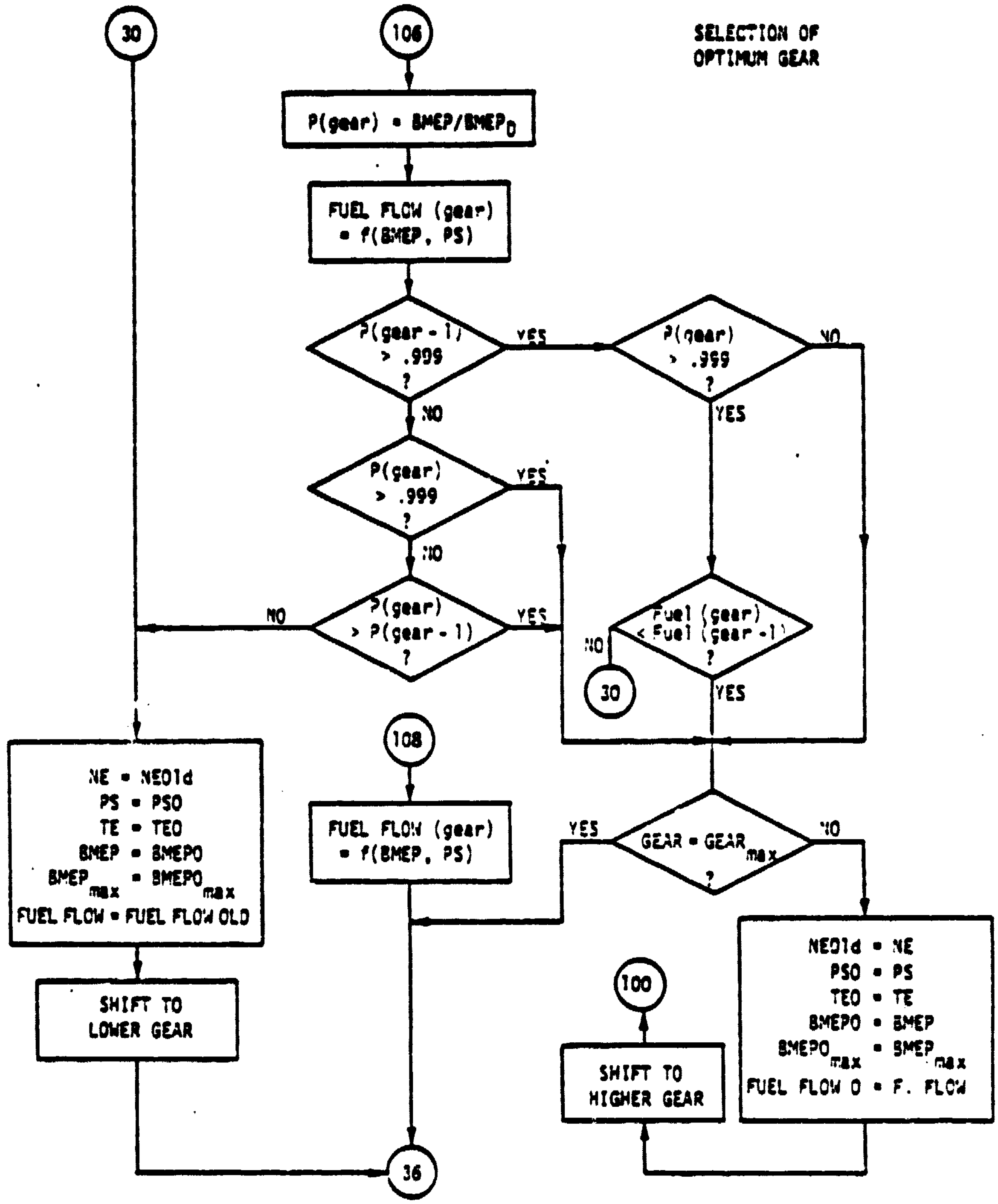

100
REQUIRED ENGINE SPEED, TORQUE
ENGINE SPEED = NG = NE f(VEH. SP., GEAR RATIO, TIRE RADIUS)
SHIFT TO HIGHER GEAR
NE < NE max ?
NO
GEAR = GEAR max ?
NO
YES
YES
PISTON SP. = PS
EN. TORQUE = TE
A
VEH. SP. ≤ 0 ?
YES
NO
CAR NOT TO CONTINUE THIS CYCLE
80
TE = TGL = SPIN LOSS IN GEAR BOX
GEAR = PREVIOUS GEAR
B
903
BMEPD = 150.8*TE/DISPLACE.
AVAILABILITY OF ENGINE SPEED, TORQUE
GEAR = PREVIOUS GEAR ?
NO
YES
BMEPD > BMEPidle ?
NO
YES
900
107
107
NE = NE* GEAR RATIO OLD / GEAR RATIO NEW
PS = NE* STROKE / 6.
SHIFT TO LOWER GEAR
CALL PSBMEP INTERPOLATE BMEP & PS
BMEP > BMEPidle ?
NO
NE > NEidle ?
NO
GEAR = 1 ?
NO
YES
YES
YES
113
101
116

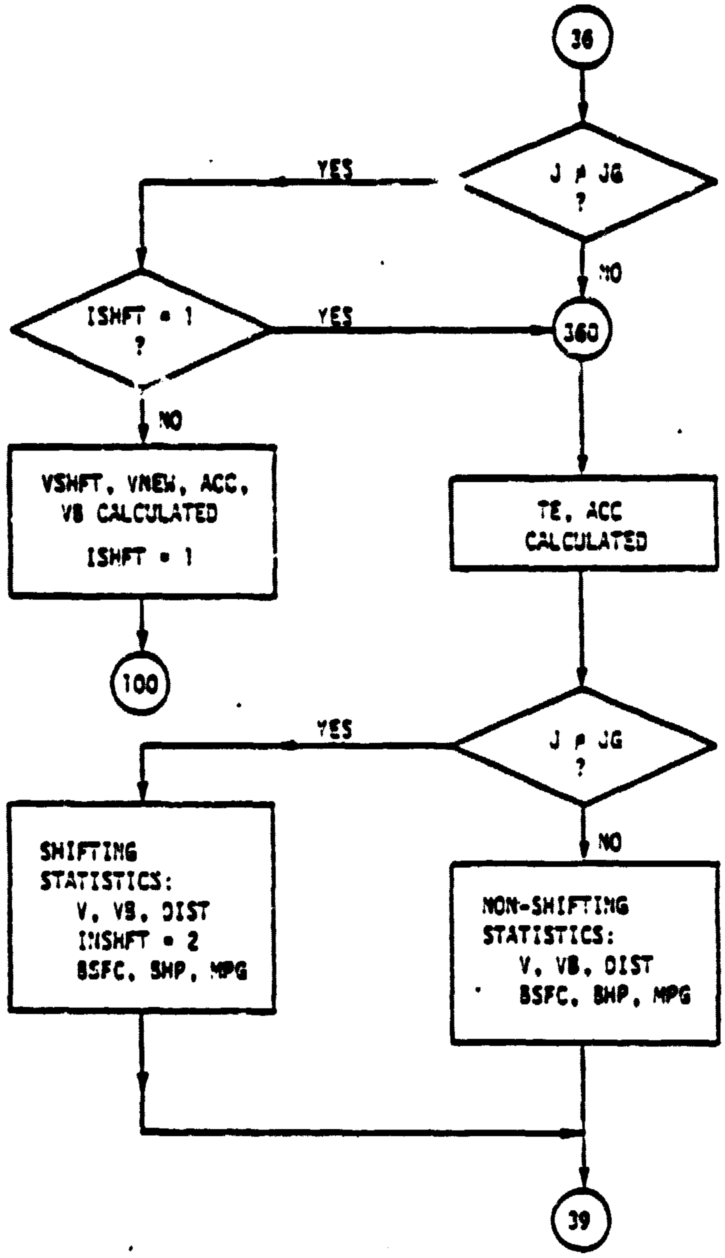


DOWNSHIFTING WHEN
COMING TO A STOP
IS ELIMINATED
900
TE ≤ 0 ?
NO
YES
V ≤ 15 mph ?
NO
YES
V ≤ 20 mph ?
V (TIME + 5 SEC) ≤ 5 mph ?
NO
YES
YES
V (TIME + 2 SEC) > 15 mph ?
YES
GEAR = PREVIOUS GEAR
BMEP = BMEP_D
NE = NE_idle
NO
GEAR = PREVIOUS GEAR
BMEP = GMEP_D
108
101
903

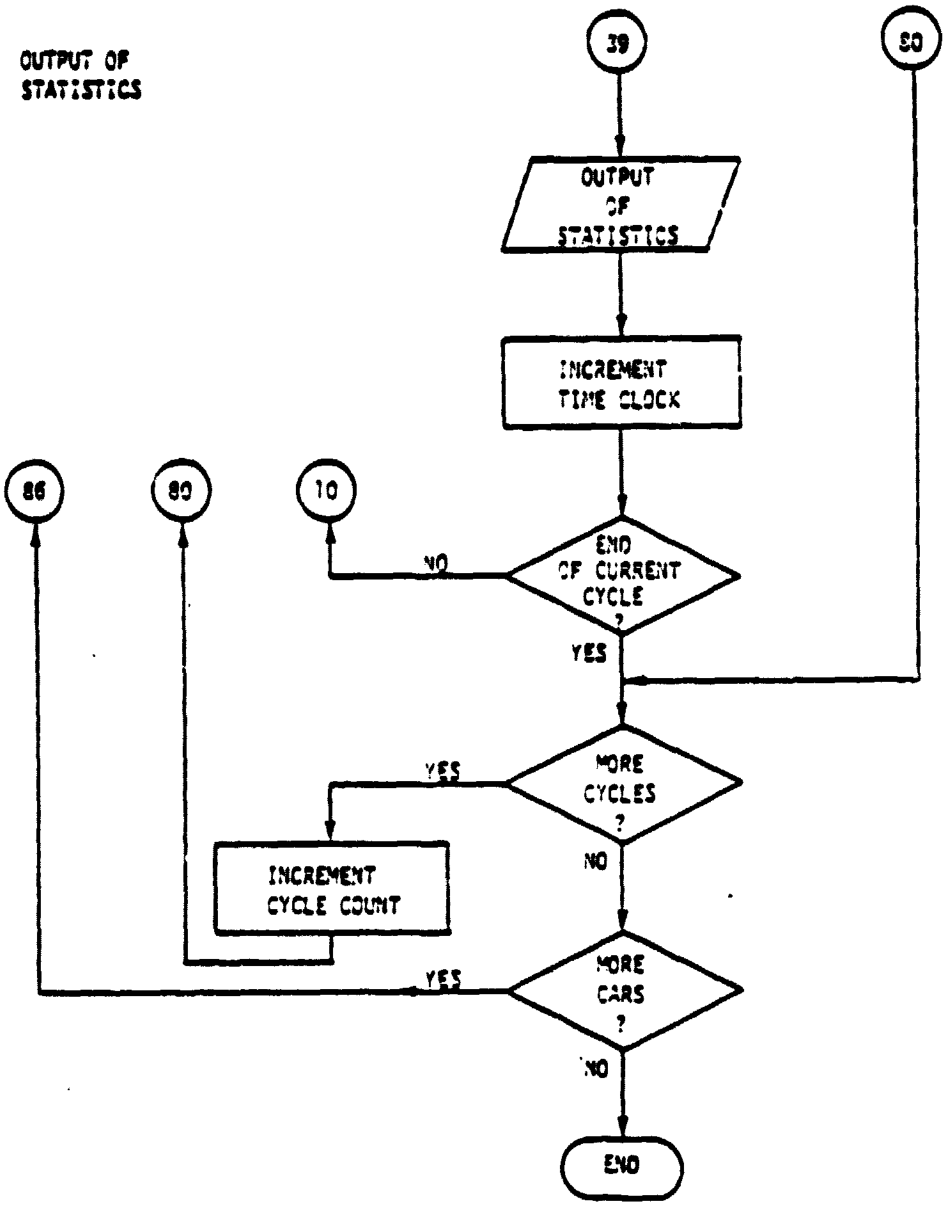


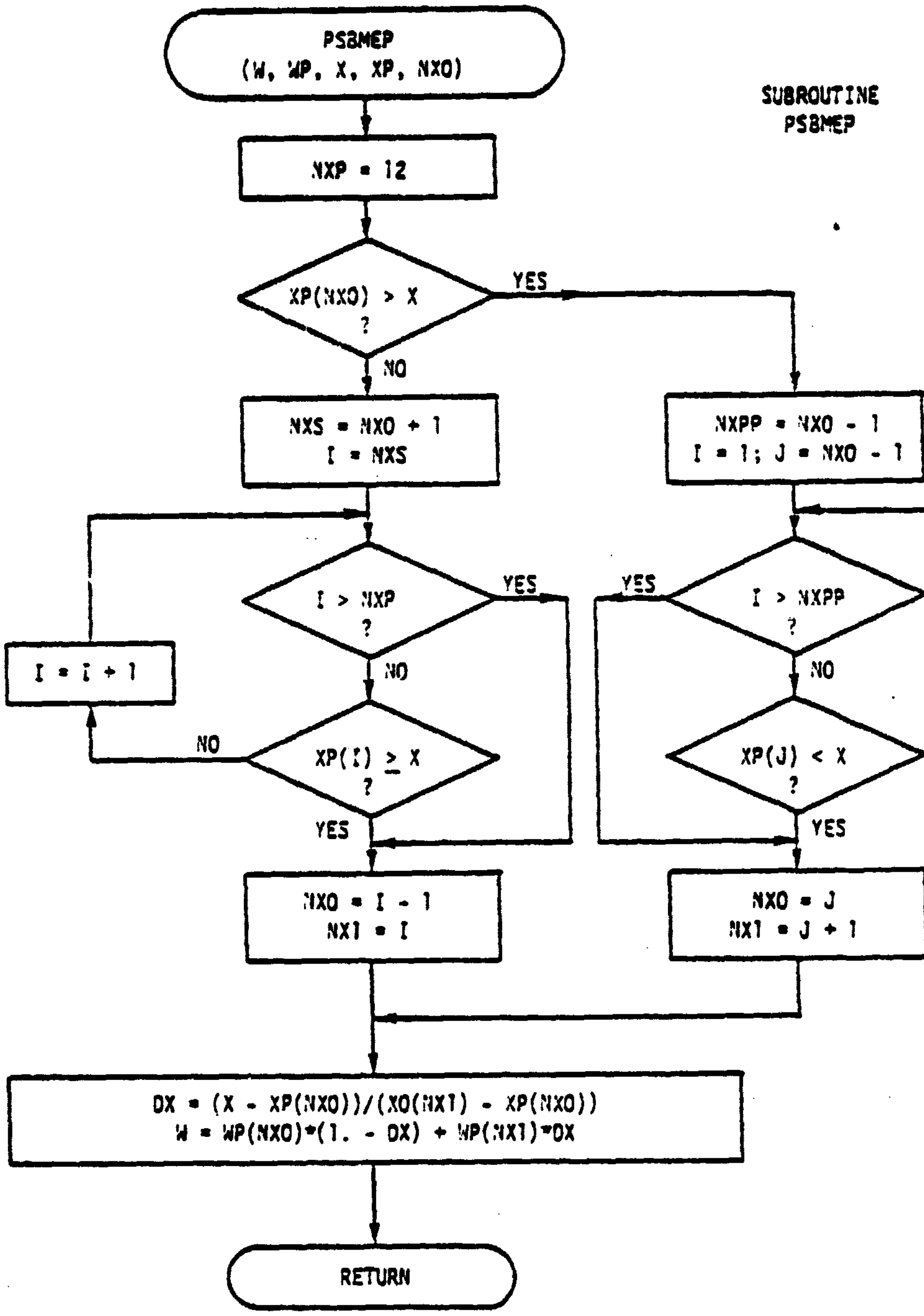
SLIPPAGE OF CLUTCH
113
NG > NE idle ?
NO
YES
GEAR = 1 ?
BMEP < BMEP max ?
GEAR = 1 ?
NE < NE max TORQUE ?
BMEP D = BMEP max
BMEP < BMEP max TORQUE ?
CALL PSBMEP INTERPOLATE PS & BMEP
NE slip = PS*6/STK
NE = NE slip
PS = NE*STK/6
BMEP = BMEP max TORQUE
NE = NE max TE
PS = NE x STK 16.
101
BMEP > BMEP min ?
BMEP = BMEP min
116
NE = NE idle
PS = NE*STR/6.
BMEP = BMEP idle
30
109
105


SELECTION OF
OPTIMUM GEAR
30
106
P(gear) = BMEP/BMEP$_0$
FUEL FLOW (gear)
= f(BMEP, PS)
P(gear - 1)
> .999
?
YES
NO
P(gear)
> .999
?
YES
NO
P(gear)
> .999
?
YES
NO
NO
P(gear)
> P(gear - 1)
?
YES
Fuel (gear)
< Fuel (gear -1)
?
NO
30
YES
108
NE = NEOld
PS = PSO
TE = TEO
BMEP = BMEPO
BMEP$_{max}$ = BMEPO$_{max}$
FUEL FLOW = FUEL FLOW OLD
FUEL FLOW (gear)
= f(BMEP, PS)
YES
GEAR = GEAR$_{max}$
?
NO
SHIFT TO
LOWER GEAR
100
NEOld = NE
PSO = PS
TEO = TE
BMEPO = BMEP
BMEPO$_{max}$ = BMEP$_{max}$
FUEL FLOW O = F. FLOW
SHIFT TO
HIGHER GEAR
36


38
J ≠ JG
?
YES
NO
ISHFT = 1
?
YES
360
NO
VSHFT, VNEW, ACC,
VB CALCULATED
ISHFT = 1
TE, ACC
CALCULATED
100
J ≠ JG
?
YES
NO
SHIFTING
STATISTICS:
V, VB, DIST
INSHFT = 2
BSFC, SHP, MPG
NON-SHIFTING
STATISTICS:
V, VB, DIST
BSFC, BHP, MPG
39

OUTPUT OF
STATISTICS




PSBMEP
(W, WP, X, XP, NXO)
SUBROUTINE
PSBMEP
NXP = 12
XP(NXO) > X
?
YES
NO
NXS = NXO + 1
I = NXS
NXPP = NXO - 1
I = 1; J = NXO - 1
I > NXP
?
YES
NO
I = I + 1
XP(I) ≥ X
?
NO
YES
I > NXPP
?
YES
NO
XP(J) < X
?
NO
YES
I = I + 1
NXO = I - 1
NX1 = I
NXO = J
NX1 = J + 1
DX = (X - XP(NXO))/(XO(NX1) - XP(NXO))
W = WP(NXO)*(1. - DX) + WP(NX1)*DX
RETURN

INPUT PARAMETERS
FOR CARSIM

M I N I C A R S ,   I N C .   C A R   S I M U L A T I O N

CAR DATA

WEIGHT (LBS)	DRAG COEF	FRONTAL AREA (SQ FT)	TIRES: LOW SPEED HYSTERISIS LOSS	TIRES: TRACTIVE STIFFNESS	TIRES: SPEED COEF FOR HYSTERISIS LOSS (MPH/100)	TORQUE RADIUS (INCHES)
4320.	0.39	21.00	0.0123	10.40	0.14590	13.10

GEAR DATA

GEAR NO	GEAR RATIO	GEAR INERTIA	GEAR TORQUE LOSS CONSTANTS: CONSTANT VALUE	RPM RELATED	TORQUE RELATED
1	3.450	0.056	0.100	0.000	0.050
2	1.940	0.056	0.100	0.000	0.040
3	1.240	0.056	0.100	0.000	0.030
4	0.970	0.056	0.100	0.000	0.020
5	0.750	0.056	0.100	0.000	0.020

FINAL DRIVE RATIO = 3.90

INERTIA DATA

. INERTIA (LBM FT SQ) . ENGINE	FINAL DRIVE	FOUR WHEELS	SPIN TORQUE LOSS (LBM FT SQ) FINAL DRIVE	EFFICIENCY FINAL DRIVE
2.91	0.278	78.73	0.18	1.00

ENGINE DATA

******* SCALED ENGINE USED *******

BORE (IN)	STROKE (IN)	CYLINDERS	IDLE SPEED (RPM)	MAX TORQUE SPEED (RPM)	MAX TORQUE (FT/LB)	MAX ALLOWED SPEED (RPM)	MIN ALLOWED SPEED (RPM)	MOTORED TORQUE (FT/LB)	ENGINE SCALE FACTOR (%)
3.010	3.150	4.	1000.	3000.	81.	5000.	1000.	-20.24	92.00

M I N I C A R S , I N C . C A R S I M U L A T I O N

FUEL DATA
---- ----

SPEED (RPM) — TORQUE (FT/LBS) / FUEL CONSUMPTION (LBS/HR)

SPEED (RPM)												
1000.	-50.00	-18.00	24.20	43.20	58.70							
	0.00	0.00	2.65	4.19	6.25							
1500.	-50.00	-20.00	16.00	21.60	28.50	33.80	30.80	47.50	58.70	63.00	65.60	
	0.00	0.00	3.00	3.55	4.01	4.61	5.11	6.19	7.72	8.58	9.02	
2000.	-50.00	-22.00	14.70	21.10	27.60	33.20	36.10	47.50	60.40	70.80	76.80	82.40
	0.00	0.00	3.68	4.63	5.19	6.03	6.36	8.03	10.21	12.41	13.95	15.23
2500.	-50.00	-25.00	15.50	22.90	29.30	34.50	30.40	48.30	72.50	84.20	86.70	
	0.00	0.00	4.86	6.27	6.89	7.84	8.42	10.21	15.32	18.44	19.35	
3000.	-50.00	-27.00	12.90	18.10	24.20	32.10	37.50	43.60	55.70	75.10	85.00	88.00
	0.00	0.00	5.47	6.81	7.94	9.12	10.23	11.46	14.12	19.04	22.36	23.81
3500.	-50.00	-30.00	15.10	19.40	25.90	36.30	43.60	51.40	67.80	79.40	85.00	86.70
	0.00	0.00	7.45	8.50	9.93	11.92	13.85	15.76	20.19	24.36	27.02	27.75
4000.	-50.00	-34.00	13.80	18.10	22.40	30.60	43.20	54.80	66.50	76.40	82.40	
	0.00	0.00	8.65	10.21	11.24	13.43	16.21	19.90	23.47	27.74	30.60	
4500.	-50.00	-38.00	17.30	21.20	25.90	36.30	56.10	70.00	[illegible].30			
	0.00	0.00	12.16	13.41	14.59	17.88	23.71	29.91	[illegible]2.98			
5000.	-50.00	-41.00	21.60	25.50	33.70	45.70	64.70	69.10				
	0.00	0.00	16.89	17.94	21.08	25.06	33.44	36.21				

FUEL DENSITY = 7.06

MAXIMUM TORQUE DATA
------- ------ ----

ENGINE SPEED (RPM)	0.	500.	1000.	1500.	2000.	2500.	3000.	3500.	4000.	4500.	5000.	5500.
MAXIMUM TORQUE	0.0	50.8	53.2	60.4	75.8	79.8	81.0	79.8	75.8	69.5	63.6	55.6

MINICARS, INC. CAR SIMULATION

ELECTRIC MOTOR DATA

INERTIA (LBM FT SQ)	RESISTANCE (OHMS) ARMATURE	FIELD	.... TORQUE LOSS CONSTANTS ...... LB FT/RPM SQ	LB FT/RPM	LB FT	MIN SPEED (RPM)	DISCHARGING MAX ALLOWED SPEED (RPM)	MAX ARMATURE CURRENT (AMPS)	CHARGING MAX ARMATURE CURRENT (AMPS)
2.019	0.0037	2.4100	0.98500E-07	0.10000E-03	0.8050	1650.	5500.	308.	308.

MAX FIELD CURRENT * BASELINE RPM (AMPS*RPM)	BASELINE RPM	FIELD CONTROLLER EFFICIENCY * FIELD VOLTAGE / BATTERY OPEN CIRCUIT VOLTAGE
10721.003	650.000	0.780

TRANSMISSION DATA

SHIFT CURVES - INTERNAL COMBUSTION ENGINE

FIRST GEAR	UPSHIFT RPM	1825	1828	1832	3450	4899	4902		
	UPSHIFT TORQUE	-919.1	0.0	21.9	36.0	38.9	919.1		
	DOWNSHIFT RPM	-3450	-3445	-3440					
	DOWNSHIFT TORQUE	-919.1	0.0	919.1					
SECOND GEAR	UPSHIFT RPM	1591	1593	1597	2910	3290	4976	4986	4988
	UPSHIFT TORQUE	-919.1	0.0	23.7	17.9	43.1	45.1	61.6	919.1
	DOWNSHIFT RPM	1007	1009	1011	1261	1940	2425	2427	
	DOWNSHIFT TORQUE	-919.1	0.0	42.7	53.1	71.1	75.9	919.1	
THIRD GEAR	UPSHIFT RPM	1301	1302	1303	1860	3100	3720	4985	4991
	UPSHIFT TORQUE	-919.1	0.0	22.3	33.4	48.2	54.2	51.2	919.1
	DOWNSHIFT RPM	1004	1006	1007	1860	2108	2877	2883	2884
	DOWNSHIFT TORQUE	-919.1	0.0	40.8	65.3	75.7	77.9	96.4	919.1
FOURTH GEAR	UPSHIFT RPM	1305	1310	1314	2910	3395	4991	4996	
	UPSHIFT TORQUE	-919.1	0.0	19.0	45.5	55.9	51.2	919.1	
	DOWNSHIFT RPM	1008	1009	1010	1455	2425	2910	3511	3516
	DOWNSHIFT TORQUE	-919.1	0.0	31.3	47.4	60.3	77.7	71.3	919.1
FIFTH GEAR	UPSHIFT RPM	4984	4988	4991					
	UPSHIFT TORQUE	-919.1	0.0	919.1					
	DOWNSHIFT RPM	1001	1005	1009	2250	2625	3404	3408	
	DOWNSHIFT TORQUE	-919.1	0.0	27.3	65.0	79.8	71.6	919.1	

SHIFT CURVES - ELECTRIC ENGINE

FIRST GEAR	UPSHIFT RPM	4950	4963	4976
	UPSHIFT TORQUE	-999.0	0.0	999.0
	DOWNSHIFT RPM	-5023	-5013	-5030

	DOWNSHIFT TORQUE	-999.0	0.0	999.0
SECOND GEAR	UPSHIFT RPM	4950	4960	4970
	UPSHIFT TORQUE	-999.0	0.0	999.0
	DOWNSHIFT RPM	1660	1670	1680
	DOWNSHIFT TORQUE	-999.0	0.0	999.0
THIRD GEAR	UPSHIFT RPM	4950	4960	4970
	UPSHIFT TORQUE	-999.0	0.0	999.0
	DOWNSHIFT RPM	1660	1670	1680
	DOWNSHIFT TORQUE	-999.0	0.0	999.0
FOURTH GEAR	UPSHIFT RPM	4950	4960	4970
	UPSHIFT TORQUE	-999.0	0.0	999.0
	DOWNSHIFT RPM	1660	1670	1680
	DOWNSHIFT TORQUE	-999.0	0.0	999.0
FIFTH GEAR	UPSHIFT RPM	4950	4960	4970
	UPSHIFT TORQUE	-999.0	0.0	999.0
	DOWNSHIFT RPM	1660	1670	1680
	DOWNSHIFT TORQUE	-999.0	0.0	999.0

SHIFT CURVES - HYBRID MODE

FIRST GEAR	UPSHIFT RPM	4950	4960	4970
	UPSHIFT TORQUE	-999.0	0.0	999.0
	DOWNSHIFT RPM	-5020	-5010	-5000
	DOWNSHIFT TORQUE	-999.0	0.0	999.0
SECOND GEAR	UPSHIFT RPM	4950	4960	4970
	UPSHIFT TORQUE	-999.0	0.0	999.0
	DOWNSHIFT RPM	1660	1670	1680
	DOWNSHIFT TORQUE	-999.0	0.0	999.0
THIRD GEAR	UPSHIFT RPM	4950	4960	4970
	UPSHIFT TORQUE	-999.0	0.0	999.0
	DOWNSHIFT RPM	1660	1670	1680
	DOWNSHIFT TORQUE	-999.0	0.0	999.0
FOURTH GEAR	UPSHIFT RPM	4950	4960	4970
	UPSHIFT TORQUE	-999.0	0.0	999.0
	DOWNSHIFT RPM	1660	1670	1680
	DOWNSHIFT TORQUE	-999.0	0.0	999.0
FIFTH GEAR	UPSHIFT RPM	4950	4960	4970
	UPSHIFT TORQUE	-999.0	0.0	999.0
	DOWNSHIFT RPM	1660	1670	1680
	DOWNSHIFT TORQUE	-999.0	0.0	999.0

BATTERY DATA

DISCHARGE INITIAL STATE	DISCHARGE CUTOFF VALUE	OPEN CIRCUIT INITIAL VOLTAGE	INTERNAL BATTERY RESISTANCES (OHMS) 1	2	DISCHARGE VOLTAGE DEPRESSION CONSTANT	BATTERY CAPACITY (AMP-HR)	... DISCHARGE MODEL CONSTANTS ... A	B	C

0.0000	0.0000	96.000	0.005700	0.024300	7.75000	175.0000	5.7380	-0.969900	-0.040200

HYBRID MODE DATA
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MAX HYBRID RPM	MIN HYBRID RPM
5000.	1750.

ACCESSORY SELECTION AND DATA
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ALTERNATOR ON (1=YES)	FAN ON (1=YES)	PUMP ON (1=YES)	ALTERNATOR TORQUE (FT/LB)	FAN TORQUE (FT/LB)	PUMP TORQUE (FT/LB)
0	0	0	1.00	1.00	1.00

ENGINE/MOTOR SELECTION DATA
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MODE OF OPERATION	OPERATION QUALIFIER	HYBRID SPLIT	CURRENT OFF REGENERATIVE BRAKING	CURRENT OFF DURING DECELS	.....FUEL OFF..... DURING IDLE	.....FUEL OFF..... DURING DECELS	DURING IDLE
2	0	1	1	0	0	0	0

ORIGINAL

COMMENT	KEY
NORMAL	0
GEAR CHANGE	1
SLIPPING' CLUTCH	3
IDLE	5
HYBRID REQUESTED	10
DECELERATION	100
POWER LIMITED	300
RPM LIMITED	500

DETAILED OUTPUT INFORMATION FOR
FHDC, WITH ELECTRIC MOTOR
PRIMARY DRIVE

EPA HIGHWAY DRIVING CYCLE (765 SECONDS)

TIME	VEL	DV	ACC	DIST	J	NE	TE	BHPE	LB/HR	BSFC	MPG	NM	TM	BHPM	IARM	IFLD	EB	EFFM	KWHR	S	EMPG	M	COM
1.00	0.0	0.0	0.00	0.00	1	0	0.0	0.0	0.000	0.000	0.0	1650	0.9	0.3	6.1	12.2	71.6	16.61	0.000	0.0000	0.0	2	5
2.00	0.0	0.0	0.00	0.00	1	0	0.0	0.0	0.000	0.000	0.0	1650	0.9	0.3	6.1	12.2	71.6	16.61	0.001	0.0000	0.0	2	5
3.00	0.0	0.0	0.00	0.00	1	0	0.0	0.0	0.000	0.000	0.0	1650	0.9	0.3	6.1	12.2	71.6	16.61	0.001	0.0001	0.0	2	5
4.00	2.0	0.0	2.00	0.00	1	0	0.0	0.0	0.000	0.000	0.0	1650	57.2	11.7	131.4	12.2	66.8	88.17	0.004	0.0004	0.0	2	3
5.00	4.9	0.0	2.90	0.00	1	0	0.0	0.0	0.000	0.000	0.0	1650	52.0	16.3	187.0	12.2	67.5	90.80	0.008	0.0008	0.0	2	3
6.00	8.1	0.0	3.20	0.00	1	0	0.0	0.0	0.000	0.000	0.0	1650	57.1	17.9	206.8	12.2	67.1	91.09	0.012	0.0014	0.0	2	3
7.00	11.3	0.0	3.20	0.01	1	0	0.0	0.0	0.000	0.000	0.0	1714	57.3	18.7	216.5	11.5	66.9	91.50	0.016	0.0019	0.0	2	0
8.00	14.5	0.0	3.20	0.01	1	0	0.0	0.0	0.000	0.000	0.0	2277	57.5	24.9	300.4	7.5	65.1	92.87	0.021	0.0026	0.0	2	0
9.00	17.3	0.0	2.80	0.01	1	0	0.0	0.0	0.000	0.000	0.0	2794	51.2	27.2	335.2	5.7	64.3	92.62	0.028	0.0038	0.0	2	0
10.00	19.6	0.0	2.30	0.02	1	0	0.0	0.0	0.000	0.000	0.0	3222	43.1	26.5	327.7	4.8	64.3	92.05	0.033	0.0048	0.0	2	0
11.00	21.8	0.0	2.20	0.02	1	0	0.0	0.0	0.000	0.000	0.0	3608	41.7	28.7	362.7	4.1	63.7	91.41	0.040	0.0059	0.0	2	0
12.00	24.0	0.0	2.20	0.03	1	0	0.0	0.0	0.000	0.000	0.0	3986	41.9	31.8	415.3	3.7	62.5	90.63	0.047	0.0072	0.0	2	0
13.00	25.8	0.0	1.80	0.04	1	0	0.0	0.0	0.000	0.000	0.0	4319	35.5	29.2	379.9	3.3	63.3	89.75	0.054	0.0084	0.0	2	0
14.00	27.1	0.0	1.30	0.05	1	0	0.0	0.0	0.000	0.000	0.0	4564	27.4	23.8	306.2	3.1	65.0	88.33	0.060	0.0093	0.0	2	0
15.00	28.0	0.0	0.90	0.05	1	0	0.0	0.0	0.000	0.000	0.0	4736	20.9	18.8	242.6	3.0	66.4	86.12	0.064	0.0099	0.0	2	0
16.00	29.0	0.0	1.00	0.06	1	0	0.0	0.0	0.000	0.000	0.0	4899	22.7	21.1	275.1	2.9	65.7	86.30	0.069	0.0107	0.0	2	0
17.00	29.4	0.0	1.07	0.07	2	0	0.0	0.0	0.000	0.000	0.0	2813	40.9	11.7	146.5	4.7	65.9	92.33	0.072	0.0114	0.0	2	1
18.00	30.7	0.0	1.35	0.08	2	0	0.0	0.0	0.000	0.000	0.0	2910	49.2	27.2	336.5	5.4	64.2	92.50	0.078	0.0124	0.0	2	0
19.00	31.5	0.0	0.80	0.09	2	0	0.0	0.0	0.000	0.000	0.0	2997	33.8	19.3	230.2	5.2	66.6	91.69	0.082	0.0130	0.0	2	0
20.00	32.2	0.0	0.70	0.09	2	0	0.0	0.0	0.000	0.000	0.0	3067	31.1	18.2	216.6	5.1	66.9	91.33	0.086	0.0136	0.0	2	0
21.00	32.9	0.0	0.70	0.10	2	0	0.0	0.0	0.000	0.000	0.0	3133	31.3	18.7	223.2	4.9	66.8	91.31	0.090	0.0141	0.0	2	0
22.00	33.5	0.0	0.60	0.11	2	0	0.0	0.0	0.000	0.000	0.0	3191	28.6	17.4	207.4	4.8	67.1	90.87	0.094	0.0146	0.0	2	0
23.00	34.1	0.0	0.60	0.12	2	0	0.0	0.0	0.000	0.000	0.0	3249	28.7	17.8	212.9	4.7	67.0	90.85	0.098	0.0152	0.0	2	0
24.00	34.6	0.0	0.50	0.13	2	0	0.0	0.0	0.000	0.000	0.0	3298	26.0	16.3	195.4	4.6	67.4	90.30	0.102	0.0156	0.0	2	0
25.00	34.9	0.0	0.30	0.14	2	0	0.0	0.0	0.000	0.000	0.0	3329	20.4	12.9	154.6	4.6	68.3	88.66	0.105	0.0160	0.0	2	0
26.00	35.1	0.0	0.20	0.15	2	0	0.0	0.0	0.000	0.000	0.0	3350	17.6	11.2	134.8	4.5	68.6	87.40	0.108	0.0165	0.0	2	0
27.00	35.7	0.0	0.60	0.16	2	0	0.0	0.0	0.000	0.000	0.0	3400	29.1	18.8	227.8	4.4	66.7	90.77	0.112	0.0169	0.0	2	0
28.00	35.9	0.0	0.20	0.17	2	0	0.0	0.0	0.000	0.000	0.0	3426	17.8	11.6	139.8	4.4	68.6	87.43	0.115	0.0172	0.0	2	0
29.00	35.8	0.0	-0.10	0.18	2	0	0.0	0.0	0.000	0.000	0.0	3422	9.3	6.0	76.4	4.4	70.1	79.46	0.117	0.0173	0.0	2	0
30.00	35.3	0.0	-0.50	0.19	2	0	0.0	0.0	0.000	0.000	0.0	3381	-2.2	-1.4	-3.7	4.5	71.9	79.46	0.117	0.0173	0.0	2	100
31.00	34.9	0.0	-0.40	0.20	2	0	0.0	0.0	0.000	0.000	0.0	3342	0.5	0.3	14.4	4.5	71.5	16.60	0.117	0.0173	0.0	2	0
32.00	34.5	0.0	-0.40	0.21	2	0	0.0	0.0	0.000	0.000	0.0	3303	0.4	0.3	13.5	4.6	71.5	15.92	0.117	0.0173	0.0	2	0
33.00	34.6	0.0	0.10	0.22	2	0	0.0	0.0	0.000	0.000	0.0	3305	14.6	9.2	111.3	4.6	69.3	85.60	0.120	0.0176	0.0	2	0
34.00	34.8	0.0	0.20	0.23	2	0	0.0	0.0	0.000	0.000	0.0	3321	17.5	11.1	133.6	4.6	68.8	87.38	0.122	0.0178	0.0	2	0
35.00	35.1	0.0	0.30	0.24	2	0	0.0	0.0	0.000	0.000	0.0	3348	20.4	13.0	156.0	4.5	68.3	88.66	0.125	0.0182	0.0	2	0
36.00	35.7	0.0	0.60	0.25	2	0	0.0	0.0	0.000	0.000	0.0	3400	29.1	18.8	227.8	4.4	66.6	90.76	0.129	0.0188	0.0	2	0
37.00	36.1	0.0	0.40	0.26	2	0	0.0	0.0	0.000	0.000	0.0	3441	23.5	15.4	185.5	4.4	67.6	89.56	0.133	0.0192	0.0	2	0
38.00	36.2	0.0	0.10	0.27	2	0	0.0	0.0	0.000	0.000	0.0	3455	15.0	9.9	120.1	4.4	69.1	85.74	0.135	0.0195	0.0	2	0
39.00	36.5	0.0	0.30	0.28	2	0	0.0	0.0	0.000	0.000	0.0	3480	26.8	13.8	165.9	4.3	68.0	88.65	0.139	0.0198	0.0	2	0
40.00	36.7	0.0	0.20	0.29	2	0	0.0	0.0	0.000	0.000	0.0	3501	18.0	12.0	145.0	4.3	68.5	87.45	0.141	0.0202	0.0	2	0
41.00	36.9	0.0	0.20	0.30	2	0	0.0	0.0	0.000	0.000	0.0	3519	18.0	12.1	146.3	4.3	68.5	87.45	0.144	0.0205	0.0	2	0
42.00	37.0	0.0	0.10	0.31	2	0	0.0	0.0	0.000	0.000	0.0	3530	15.2	10.2	124.8	4.2	69.0	85.79	0.147	0.0207	0.0	2	0
43.00	37.0	0.0	0.00	0.32	2	0	0.0	0.0	0.000	0.000	0.0	3532	12.4	8.3	103.0	4.2	69.5	83.41	0.149	0.0209	0.0	2	0
44.00	37.0	0.0	0.00	0.33	2	0	0.0	0.0	0.000	0.000	0.0	3532	12.4	8.3	103.0	4.2	69.5	83.41	0.151	0.0211	0.0	2	0
45.00	37.0	0.0	0.00	0.34	2	0	0.0	0.0	0.000	0.000	0.0	3532	12.4	8.3	103.0	4.2	69.5	83.41	0.153	0.0213	0.0	2	0
46.00	37.0	0.0	0.00	0.35	2	0	0.0	0.0	0.000	0.000	0.0	3532	12.4	8.3	103.0	4.2	69.5	83.41	0.155	0.0215	0.0	2	0
47.00	37.0	0.0	0.00	0.36	2	0	0.0	0.0	0.000	0.000	0.0	3532	12.4	8.3	103.0	4.2	69.5	83.41	0.157	0.0217	0.0	2	0
48.00	37.1	0.0	0.10	0.37	2	0	0.0	0.0	0.000	0.000	0.0	3540	15.3	10.3	125.4	4.2	68.9	85.80	0.160	0.0220	0.0	2	0
49.00	37.3	0.0	0.20	0.38	2	0	0.0	0.0	0.000	0.000	0.0	3557	16.1	12.3	149.0	4.2	68.4	87.45	0.163	0.0223	0.0	2	0
50.00	37.8	0.0	0.50	0.39	2	0	0.0	0.0	0.000	0.000	0.0	3600	26.8	18.4	223.7	4.1	66.7	96.12	0.167	0.0229	0.0	2	0
51.00	38.6	0.0	0.80	0.40	2	0	0.0	0.0	0.000	0.000	0.0	3670	35.5	24.8	309.8	4.1	64.8	91.07	0.172	0.0238	0.0	2	0
52.00	39.3	0.0	0.70	0.41	2	0	0.0	0.0	0.000	0.000	0.0	3738	32.9	23.4	291.0	4.0	65.2	90.74	0.178	0.0246	0.0	2	0
53.00	40.0	0.0	0.70	0.42	2	0	0.0	0.0	0.000	0.000	0.0	3804	33.1	23.9	299.2	3.9	65.0	90.65	0.183	0.0254	0.0	2	0
54.00	40.7	0.0	0.70	0.44	2	0	0.0	0.0	0.000	0.000	0.0	3870	33.3	24.5	307.6	3.8	64.8	90.54	0.189	0.0265	0.0	2	0
55.00	41.4	0.0	0.70	0.45	2	0	0.0	0.0	0.000	0.000	0.0	3936	33.5	25.1	316.3	3.7	64.6	90.43	0.195	0.0272	0.0	2	0
56.00	42.2	0.0	0.80	0.46	2	0	0.0	0.0	0.000	0.000	0.0	4009	36.5	27.9	357.4	3.6	63.7	90.47	0.201	0.0283	0.0	2	0
57.00	42.9	0.0	0.70	0.47	2	0	0.0	0.0	0.000	0.000	0.0	4077	33.9	26.3	335.6	3.6	64.2	90.18	0.207	0.0293	0.0	2	0
58.00	43.5	0.0	0.60	0.48	2	0	0.0	0.0	0.000	0.000	0.0	4134	31.2	24.6	311.9	3.5	64.7	89.83	0.213	0.0302	0.0	2	0
59.00	44.0	0.0	0.50	0.49	2	0	0.0	0.0	0.000	0.000	0.0	4182	28.5	22.7	287.0	3.5	65.2	89.37	0.218	0.0310	0.0	2	0

60.00	44.3	0.0	0.30	0.51	2	0	0.0	0.0	0.000	0.000	0.0	4211	22.9	16.4	230.4	3.4	66.5	86.09	0.222	0.0316	0.0	2	0
61.00	44.5	0.0	0.20	0.52	2	0	0.0	0.0	0.000	0.000	0.0	4235	26.1	16.2	203.6	3.4	67.1	87.08	0.226	0.0321	0.0	2	0
62.00	44.8	0.0	0.30	0.53	2	0	0.0	0.0	0.000	0.000	0.0	4260	23.1	18.7	235.3	3.4	66.4	88.03	0.231	0.0327	0.0	2	0
63.00	44.9	0.0	0.10	0.54	2	0	0.0	0.0	0.000	0.000	0.0	4269	17.4	14.1	176.5	3.4	67.7	85.70	0.234	0.0331	0.0	2	0
64.00	45.0	0.0	0.10	0.56	2	0	0.0	0.0	0.000	0.000	0.0	4279	17.4	14.2	179.3	3.4	67.7	85.70	0.237	0.0335	0.0	2	0
65.00	45.1	0.0	0.10	0.57	2	0	0.0	0.0	0.000	0.000	0.0	4289	17.5	14.3	180.1	3.4	67.4	85.69	0.241	0.0340	0.0	2	0
66.00	45.4	0.0	0.30	0.58	2	0	0.0	0.0	0.000	0.000	0.0	4314	23.3	19.1	241.6	3.3	66.3	87.96	0.245	0.0346	0.0	2	0
67.00	45.7	0.0	0.30	0.59	2	0	0.0	0.0	0.000	0.000	0.0	4343	23.3	19.3	244.1	3.3	66.2	87.92	0.250	0.0352	0.0	2	0
68.00	46.0	0.0	0.30	0.61	2	0	0.0	0.0	0.000	0.000	0.0	4370	23.4	19.5	247.0	3.3	66.1	87.86	0.254	0.0359	0.0	2	0
69.00	46.3	0.0	0.30	0.62	2	0	0.0	0.0	0.000	0.000	0.0	4399	23.5	19.7	250.1	3.3	66.0	87.84	0.259	0.0365	0.0	2	0
70.00	46.5	0.0	0.20	0.63	2	0	0.0	0.0	0.000	0.000	0.0	4419	20.7	17.5	221.4	3.2	66.7	86.88	0.263	0.0371	0.0	2	0
71.00	46.8	0.0	0.30	0.65	2	0	0.0	0.0	0.000	0.000	0.0	4446	23.7	20.1	255.2	3.2	65.9	87.77	0.268	0.0378	0.0	2	0
72.00	46.9	0.0	0.10	0.66	2	0	0.0	0.0	0.000	0.000	0.0	4456	18.0	15.3	194.8	3.2	67.3	85.56	0.272	0.0382	0.0	2	0
73.00	47.0	0.0	0.10	0.67	2	0	0.0	0.0	0.000	0.000	0.0	4465	18.1	15.3	195.7	3.2	67.3	85.55	0.275	0.0387	0.0	2	0
74.00	47.1	0.0	0.10	0.69	2	0	0.0	0.0	0.000	0.000	0.0	4475	18.1	15.4	196.5	3.2	67.2	85.55	0.279	0.0392	0.0	2	0
75.00	47.2	0.0	0.10	0.70	2	0	0.0	0.0	0.000	0.000	0.0	4485	18.1	15.5	197.4	3.2	67.2	85.54	0.283	0.0396	0.0	2	0
76.00	47.3	0.0	0.10	0.71	2	0	0.0	0.0	0.000	0.000	0.0	4494	18.1	15.5	196.3	3.2	67.2	85.53	0.287	0.0401	0.0	2	0
77.00	47.2	0.0	-0.10	0.72	2	0	0.0	0.0	0.000	0.000	0.0	4487	12.4	10.6	138.9	3.2	68.5	81.19	0.289	0.0404	0.0	2	0
78.00	47.1	0.0	-0.10	0.74	2	0	0.0	0.0	0.000	0.000	0.0	4477	12.4	10.6	138.2	3.2	68.6	81.18	0.292	0.0407	0.0	2	0
79.00	47.0	0.0	-0.10	0.75	2	0	0.0	0.0	0.000	0.000	0.0	4467	12.3	10.5	137.5	3.2	68.6	81.18	0.295	0.0410	0.0	2	0
80.00	46.9	0.0	-0.10	0.76	2	0	0.0	0.0	0.000	0.000	0.0	4458	12.3	10.5	136.8	3.2	68.6	81.18	0.297	0.0413	0.0	2	0
81.00	46.9	0.0	0.00	0.78	2	0	0.0	0.0	0.000	0.000	0.0	4456	15.2	12.9	165.5	3.2	67.9	83.77	0.301	0.0416	0.0	2	0
82.00	46.9	0.0	0.00	0.79	2	0	0.0	0.0	0.000	0.000	0.0	4458	15.2	12.9	165.5	3.2	67.9	83.77	0.304	0.0420	0.0	2	0
83.00	47.0	0.0	0.10	0.80	2	0	0.0	0.0	0.000	0.000	0.0	4465	18.1	15.3	195.8	3.2	67.2	85.55	0.308	0.0425	0.0	2	0
84.00	47.1	0.0	0.10	0.82	2	0	0.0	0.0	0.000	0.000	0.0	4475	18.1	15.4	196.6	3.2	67.2	85.54	0.311	0.0430	0.0	2	0
85.00	47.1	0.0	0.00	0.83	2	0	0.0	0.0	0.000	0.000	0.0	4475	15.2	13.0	167.0	3.2	67.9	83.76	0.314	0.0433	0.0	2	0
86.00	47.2	0.0	0.10	0.84	2	0	0.0	0.0	0.000	0.000	0.0	4485	18.1	15.5	197.5	3.2	67.2	85.54	0.318	0.0438	0.0	2	0
87.00	47.1	0.0	-0.10	0.86	2	0	0.0	0.0	0.000	0.000	0.0	4477	12.4	10.6	138.3	3.2	68.5	81.18	0.321	0.0441	0.0	2	0
88.00	47.0	0.0	-0.10	0.87	2	0	0.0	0.0	0.000	0.000	0.0	4467	12.3	10.5	137.6	3.2	68.5	81.19	0.324	0.0444	0.0	2	0
89.00	46.9	0.0	-0.10	0.88	2	0	0.0	0.0	0.000	0.000	0.0	4458	12.3	10.5	136.9	3.2	68.6	81.18	0.326	0.0447	0.0	2	0
90.00	46.5	0.0	-0.40	0.89	2	0	0.0	0.0	0.000	0.000	0.0	4423	3.6	3.1	53.2	3.2	70.5	57.51	0.327	0.0448	0.0	2	0
91.00	46.3	0.0	-0.20	0.91	2	0	0.0	0.0	0.000	0.000	0.0	4403	9.3	7.8	105.4	3.3	69.3	77.09	0.329	0.0450	0.0	2	0
92.00	46.2	0.0	-0.10	0.92	2	0	0.0	0.0	0.000	0.000	0.0	4394	12.1	10.1	132.3	3.3	68.7	81.13	0.332	0.0452	0.0	2	0
93.00	46.3	0.0	0.10	0.93	2	0	0.0	0.0	0.000	0.000	0.0	4401	17.8	14.9	190.0	3.3	67.3	85.60	0.336	0.0457	0.0	2	0
94.00	46.5	0.0	0.20	0.95	2	0	0.0	0.0	0.000	0.000	0.0	4419	20.7	17.5	221.6	3.2	66.6	86.88	0.340	0.0462	0.0	2	0
95.00	46.9	0.0	0.40	0.96	2	0	0.0	0.0	0.000	0.000	0.0	4454	26.6	22.5	288.7	3.2	65.1	88.42	0.345	0.0471	0.0	2	0
96.00	47.1	0.0	0.20	0.97	2	0	0.0	0.0	0.000	0.000	0.0	4475	20.9	17.6	227.3	3.2	66.5	86.81	0.349	0.0476	0.0	2	0
97.00	47.4	0.0	0.30	0.98	2	0	0.0	0.0	0.000	0.000	0.0	4502	23.9	20.5	261.8	3.2	65.7	87.68	0.354	0.0483	0.0	2	0
98.00	47.7	0.0	0.30	1.00	2	0	0.0	0.0	0.000	0.000	0.0	4529	24.0	20.7	265.0	3.2	65.6	87.64	0.355	0.0490	0.0	2	0
99.00	48.0	0.0	0.30	1.01	2	0	0.0	0.0	0.000	0.000	0.0	4559	24.1	20.9	266.3	3.1	65.5	87.59	0.364	0.0498	0.0	2	0
100.00	48.2	0.0	0.20	1.02	2	0	0.0	0.0	0.000	0.000	0.0	4578	21.3	18.4	237.9	3.1	66.2	86.68	0.368	0.0504	0.0	2	0
101.00	48.5	0.0	0.30	1.04	2	0	0.0	0.0	0.000	0.000	0.0	4605	24.2	21.3	273.7	3.1	65.4	87.52	0.373	0.0511	0.0	2	0
102.00	48.8	0.0	0.30	1.05	2	0	0.0	0.0	0.000	0.000	0.0	4632	24.3	21.5	277.0	3.1	65.3	87.47	0.379	0.0519	0.0	2	0
103.00	49.1	0.0	0.30	1.07	2	0	0.0	0.0	0.000	0.000	0.0	4661	24.4	21.7	280.5	3.1	65.3	87.42	0.384	0.0527	0.0	2	0
104.00	49.2	0.0	0.10	1.08	2	0	0.0	0.0	0.000	0.000	0.0	4671	18.8	16.7	215.5	3.0	66.7	85.35	0.388	0.0532	0.0	2	0
105.00	49.1	0.0	-0.10	1.09	2	0	0.0	0.0	0.000	0.000	0.0	4663	13.0	11.6	152.6	3.0	68.1	81.26	0.391	0.0535	0.0	2	0
106.00	49.1	0.0	0.00	1.11	2	0	0.0	0.0	0.000	0.000	0.0	4661	15.9	14.1	183.1	3.1	67.5	83.68	0.394	0.0539	0.0	2	0
107.00	49.0	0.0	-0.10	1.12	2	0	0.0	0.0	0.000	0.000	0.0	4654	13.0	11.5	151.9	3.1	68.2	81.26	0.397	0.0543	0.0	2	0
108.00	49.0	0.0	0.00	1.13	2	0	0.0	0.0	0.000	0.000	0.0	4654	15.6	14.0	182.4	3.1	67.5	83.66	0.401	0.0547	0.0	2	0
109.00	49.1	0.0	0.10	1.15	2	0	0.0	0.0	0.000	0.000	0.0	4661	18.7	16.6	214.6	3.1	66.7	85.36	0.405	0.0552	0.0	2	0
110.00	49.2	0.0	0.10	1.16	2	0	0.0	0.0	0.000	0.000	0.0	4671	18.8	16.7	215.5	3.0	66.7	85.35	0.409	0.0558	0.0	2	0
111.00	49.3	0.0	0.10	1.17	2	0	0.0	0.0	0.000	0.000	0.0	4681	18.8	16.8	216.5	3.0	66.7	85.34	0.413	0.0563	0.0	2	0
112.00	49.4	0.0	0.10	1.19	2	0	0.0	0.0	0.000	0.000	0.0	4686	18.8	16.8	217.3	3.0	66.7	85.34	0.417	0.0568	0.0	2	0
113.00	49.5	0.0	0.10	1.20	2	0	0.0	0.0	0.000	0.000	0.0	4696	18.9	16.9	218.3	3.0	66.6	85.32	0.421	0.0574	0.0	2	0
114.00	49.5	0.0	0.00	1.22	2	0	0.0	0.0	0.000	0.000	0.0	4700	16.0	14.3	186.6	3.0	67.3	83.66	0.424	0.0578	0.0	2	0
115.00	49.5	0.0	0.00	1.23	2	0	0.0	0.0	0.000	0.000	0.0	4700	16.0	14.3	186.6	3.0	67.3	83.66	0.428	0.0583	0.0	2	0
116.00	49.4	0.0	-0.10	1.24	2	0	0.0	0.0	0.000	0.000	0.0	4690	13.1	11.7	154.9	3.0	68.1	81.27	0.431	0.0586	0.0	2	0
117.00	49.1	0.0	-0.30	1.26	2	0	0.0	0.0	0.000	0.000	0.0	4663	7.3	6.5	94.1	3.0	69.4	71.81	0.433	0.0588	0.0	2	0
118.00	48.9	0.0	-0.20	1.27	2	0	0.0	0.0	0.000	0.000	0.0	4644	10.1	8.9	121.7	3.1	68.8	77.41	0.435	0.0590	0.0	2	0
119.00	48.6	0.0	-0.30	1.28	2	0	0.0	0.0	0.000	0.000	0.0	4617	7.2	6.3	91.2	3.1	69.5	71.56	0.437	0.0592	0.0	2	0
120.00	48.4	0.0	-0.20	1.30	2	0	0.0	0.0	0.000	0.000	0.0	4597	9.9	8.7	118.4	3.1	68.9	77.52	0.439	0.0594	0.0	2	0
121.00	48.1	0.0	-0.30	1.31	2	0	0.0	0.0	0.000	0.000	0.0	4570	7.0	6.1	86.3	3.1	69.6	71.33	0.441	0.0596	0.0	2	0
122.00	47.7	0.0	-0.40	1.32	2	0	0.0	0.0	0.000	0.000	0.0	4535	4.0	3.5	58.9	3.1	70.2	59.31	0.442	0.0597	0.0	2	0

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123.00	47.4	0.0	-0.30	1.34	2	0	0.0	0.0	0.000	0.000	0.0	4506	6.6	5.6	84.5	3.2	69.7	76.56	0.444	0.0598	0.0	2	0
124.00	47.3	0.0	-0.10	1.35	2	0	0.0	0.0	0.000	0.000	0.0	4494	12.4	10.6	139.8	3.2	66.4	81.20	0.447	0.0601	0.0	2	0
125.00	47.5	0.0	0.20	1.36	2	0	0.0	0.0	0.000	0.000	0.0	4512	21.1	18.1	231.4	3.2	66.5	86.76	0.451	0.0607	0.0	2	0
126.00	47.8	0.0	0.30	1.38	2	0	0.0	0.0	0.000	0.000	0.0	4539	24.0	20.6	266.5	3.1	65.5	87.62	0.456	0.0615	0.0	2	0
127.00	47.9	0.0	0.10	1.39	2	0	0.0	0.0	0.000	0.000	0.0	4551	18.3	15.9	204.0	3.1	66.9	85.47	0.460	0.0619	0.0	2	0
128.00	48.0	0.0	0.10	1.40	2	0	0.0	0.0	0.000	0.000	0.0	4559	18.4	15.9	204.8	3.1	66.5	85.47	0.464	0.0624	0.0	2	0
129.00	47.9	0.0	-0.10	1.42	2	0	0.0	0.0	0.000	0.000	0.0	4551	12.6	10.9	144.1	3.1	68.5	81.22	0.467	0.0628	0.0	2	0
130.00	47.9	0.0	0.00	1.43	2	0	0.0	0.0	0.000	0.000	0.0	4551	15.5	13.4	173.6	3.1	67.6	83.73	0.470	0.0631	0.0	2	0
131.00	47.9	0.0	0.00	1.44	2	0	0.0	0.0	0.000	0.000	0.0	4551	15.5	13.4	173.6	3.1	67.6	83.73	0.473	0.0635	0.0	2	0
132.00	48.0	0.0	0.10	1.46	2	0	0.0	0.0	0.000	0.000	0.0	4559	18.4	15.9	204.9	3.1	66.5	85.46	0.477	0.0640	0.0	2	0
133.00	48.0	0.0	0.00	1.47	2	0	0.0	0.0	0.000	0.000	0.0	4560	15.5	13.5	174.5	3.1	67.6	83.73	0.480	0.0644	0.0	2	0
134.00	48.0	0.0	0.00	1.49	2	0	0.0	0.0	0.000	0.000	0.0	4560	15.5	13.5	174.5	3.1	67.6	83.73	0.484	0.0648	0.0	2	0
135.00	47.9	0.0	-0.10	1.50	2	0	0.0	0.0	0.000	0.000	0.0	4551	12.6	10.9	144.1	3.1	66.3	81.22	0.486	0.0652	0.0	2	0
136.00	47.3	0.0	-0.60	1.51	2	0	0.0	0.0	0.000	0.000	0.0	4498	-1.8	-1.6	4.8	3.2	71.4	81.22	0.487	0.0652	0.0	2	100
137.00	46.0	0.0	-1.30	1.52	2	0	0.0	0.0	0.000	0.000	0.0	4384	-22.2	-18.5	-162.4	3.3	75.2	81.22	0.483	0.0649	0.0	2	100
138.00	43.3	0.0	-2.70	1.54	2	0	0.0	0.0	0.000	0.000	0.0	4147	-62.8	-49.6	-425.9	3.5	81.2	81.22	0.474	0.0643	0.0	2	100
139.00	41.2	0.0	-2.10	1.55	2	0	0.0	0.0	0.000	0.000	0.0	3949	-46.3	-36.8	-308.4	3.7	78.8	81.22	0.467	0.0635	0.0	2	100
140.00	39.5	0.0	-1.70	1.56	2	0	0.0	0.0	0.000	0.000	0.0	3788	-35.3	-25.5	-229.8	3.9	76.8	81.22	0.462	0.0636	0.0	2	100
141.00	39.2	0.0	-0.30	1.57	2	0	0.0	0.0	0.000	0.000	0.0	3742	4.4	3.2	47.4	4.0	70.5	64.49	0.463	0.0636	0.0	2	0
142.00	39.0	0.0	-0.20	1.58	2	0	0.0	0.0	0.000	0.000	0.0	3722	7.2	5.1	66.9	4.0	70.0	74.76	0.465	0.0637	0.0	2	0
143.00	39.0	0.0	0.00	1.59	2	0	0.0	0.0	0.000	0.000	0.0	3720	12.9	9.1	114.2	4.0	68.9	83.42	0.467	0.0640	0.0	2	0
144.00	39.1	0.0	0.10	1.60	2	0	0.0	0.0	0.000	0.000	0.0	3728	15.8	11.2	138.2	4.0	68.4	85.86	0.470	0.0643	0.0	2	0
145.00	39.5	0.0	0.40	1.61	2	0	0.0	0.0	0.000	0.000	0.0	3761	24.4	17.5	215.0	3.9	66.6	89.34	0.474	0.0648	0.0	2	0
146.00	40.1	0.0	0.60	1.62	2	0	0.0	0.0	0.000	0.000	0.0	3814	30.2	22.8	273.9	3.9	65.3	90.31	0.479	0.0656	0.0	2	0
147.00	41.0	0.0	0.90	1.63	2	0	0.0	0.0	0.000	0.000	0.0	3895	39.0	28.9	373.7	3.8	63.0	90.75	0.485	0.0667	0.0	2	0
148.00	42.0	0.0	1.00	1.65	2	0	0.0	0.0	0.000	0.000	0.0	3988	42.2	32.0	422.4	3.7	61.9	90.55	0.493	0.0681	0.0	2	0
149.00	43.0	0.1	1.03	1.66	2	0	0.0	0.0	0.000	0.000	0.0	4085	43.2	33.6	449.6	3.6	61.3	90.29	0.500	0.0696	0.0	2	310
150.00	43.7	0.0	0.67	1.67	2	0	0.0	0.0	0.000	0.000	0.0	4153	33.4	26.4	339.8	3.5	63.8	89.55	0.507	0.0706	0.0	2	0
151.00	44.1	0.0	0.40	1.68	2	0	0.0	0.0	0.000	0.000	0.0	4192	25.7	20.5	259.2	3.5	65.6	88.82	0.511	0.0713	0.0	2	0
152.00	44.3	0.0	0.20	1.69	2	0	0.0	0.0	0.000	0.000	0.0	4213	20.1	16.1	202.7	3.4	66.9	87.10	0.515	0.0718	0.0	2	0
153.00	44.4	0.0	0.10	1.71	2	0	0.0	0.0	0.000	0.000	0.0	4225	17.3	13.9	175.4	3.4	67.5	85.73	0.518	0.0722	0.0	2	0
154.00	44.6	0.0	0.20	1.72	2	0	0.0	0.0	0.000	0.000	0.0	4240	20.2	16.3	205.3	3.4	66.8	87.07	0.522	0.0727	0.0	2	0
155.00	44.7	0.0	0.10	1.73	2	0	0.0	0.0	0.000	0.000	0.0	4252	17.3	14.0	177.8	3.4	67.4	85.71	0.526	0.0731	0.0	2	0
156.00	44.9	0.0	0.20	1.74	2	0	0.0	0.0	0.000	0.000	0.0	4269	20.3	16.5	208.0	3.4	66.7	87.04	0.530	0.0736	0.0	2	0
157.00	45.2	0.0	0.30	1.76	2	0	0.0	0.0	0.000	0.000	0.0	4297	23.2	19.0	240.3	3.4	66.0	87.97	0.534	0.0743	0.0	2	0
158.00	45.7	0.0	0.50	1.77	2	0	0.0	0.0	0.000	0.000	0.0	4341	29.0	24.0	308.6	3.3	64.4	89.67	0.540	0.0752	0.0	2	0
159.00	45.9	0.0	0.20	1.78	2	0	0.0	0.0	0.000	0.000	0.0	4363	20.6	17.1	216.9	3.3	66.5	86.96	0.544	0.0757	0.0	2	0
160.00	46.3	0.0	0.40	1.79	2	0	0.0	0.0	0.000	0.000	0.0	4397	26.4	22.1	283.1	3.3	65.0	88.50	0.549	0.0765	0.0	2	0
161.00	46.6	0.0	0.50	1.81	2	0	0.0	0.0	0.000	0.000	0.0	4444	29.4	24.9	322.2	3.2	64.1	88.88	0.555	0.0774	0.0	2	0
162.00	46.9	0.0	0.10	1.82	2	0	0.0	0.0	0.000	0.000	0.0	4456	18.0	15.3	195.7	3.2	67.0	85.56	0.558	0.0779	0.0	2	0
163.00	47.0	0.0	0.10	1.83	2	0	0.0	0.0	0.000	0.000	0.0	4465	18.1	15.3	196.6	3.2	67.0	85.55	0.562	0.0784	0.0	2	0
164.00	47.1	0.0	0.10	1.85	2	0	0.0	0.0	0.000	0.000	0.0	4475	16.1	15.4	197.4	3.2	67.0	85.54	0.566	0.0788	0.0	2	0
165.00	47.6	0.0	0.50	1.86	2	0	0.0	0.0	0.000	0.000	0.0	4520	29.6	25.5	332.6	3.2	63.9	88.73	0.572	0.0798	0.0	2	0
166.00	47.7	0.0	0.30	1.87	2	0	0.0	0.0	0.000	0.000	0.0	4549	24.0	20.8	268.2	3.1	65.3	87.40	0.577	0.0805	0.0	2	0
167.00	48.0	0.0	0.10	1.89	2	0	0.0	0.0	0.000	0.000	0.0	4559	18.4	15.9	205.3	3.1	66.8	85.46	0.581	0.0810	0.0	2	0
168.00	48.0	0.0	0.00	1.90	2	0	0.0	0.0	0.000	0.000	0.0	4560	15.5	13.5	174.6	3.1	67.5	83.72	0.584	0.0814	0.0	2	0
169.00	47.9	0.0	-0.10	1.91	2	0	0.0	0.0	0.000	0.000	0.0	4551	12.6	10.9	144.3	3.1	68.1	81.22	0.587	0.0817	0.0	2	0
170.00	47.8	0.0	-0.10	1.93	2	0	0.0	0.0	0.000	0.000	0.0	4541	12.6	10.9	143.6	3.1	68.2	81.22	0.590	0.0820	0.0	2	0
171.00	47.3	0.0	-0.50	1.94	2	0	0.0	0.0	0.000	0.000	0.0	4498	1.0	0.9	30.7	3.2	70.7	27.65	0.590	0.0821	0.0	2	0
172.00	46.7	0.0	-0.60	1.95	2	0	0.0	0.0	0.000	0.000	0.0	4444	-2.0	-1.7	2.6	3.2	71.4	27.65	0.590	0.0821	0.0	2	100
173.00	46.2	0.0	-0.50	1.97	2	0	0.0	0.0	0.000	0.000	0.0	4396	0.7	0.6	26.3	3.3	76.8	26.82	0.591	0.0821	0.0	2	0
174.00	45.9	0.0	-0.30	1.98	2	0	0.0	0.0	0.000	0.000	0.0	4366	6.3	5.2	76.8	3.3	69.7	70.11	0.592	0.0823	0.0	2	0
175.00	45.7	0.0	-0.20	1.99	2	0	0.0	0.0	0.000	0.000	0.0	4347	9.1	7.5	102.3	3.3	69.1	74.96	0.594	0.0825	0.0	2	0
176.00	45.5	0.0	-0.20	2.00	2	0	0.0	0.0	0.000	0.000	0.0	4330	9.0	7.5	101.2	3.3	69.1	76.91	0.597	0.0827	0.0	2	0
177.00	45.4	0.0	-0.10	2.02	2	0	0.0	0.0	0.000	0.000	0.0	4318	11.9	9.7	127.5	3.3	68.5	81.08	0.599	0.0829	0.0	2	0
178.00	45.3	0.0	-0.10	2.03	2	0	0.0	0.0	0.000	0.000	0.0	4303	11.8	9.7	126.9	3.3	68.5	81.07	0.601	0.0832	0.0	2	0
179.00	45.0	0.0	-0.30	2.04	2	0	0.0	0.0	0.000	0.000	0.0	4283	6.0	4.9	72.3	3.4	69.8	69.55	0.603	0.0833	0.0	2	0
180.00	44.0	0.0	-1.00	2.05	2	0	0.0	0.0	0.000	0.000	0.0	4196	-14.2	-11.3	-96.7	3.5	73.6	69.55	0.601	0.0832	0.0	2	100
181.00	43.1	0.0	-0.90	2.07	2	0	0.0	0.0	0.000	0.000	0.0	4112	-11.6	-9.1	-75.4	3.5	73.2	69.55	0.600	0.0831	0.0	2	100
182.00	42.2	0.0	-0.90	2.08	2	0	0.0	0.0	0.000	0.000	0.0	4029	-11.8	-9.1	-76.2	3.6	73.2	69.55	0.598	0.0829	0.0	2	100
183.00	41.5	0.0	-0.70	2.09	2	0	0.0	0.0	0.000	0.000	0.0	3961	-6.3	-4.8	-33.8	3.7	72.2	69.55	0.597	0.0829	0.0	2	100
184.00	41.5	0.0	0.00	2.10	2	0	0.0	0.0	0.000	0.000	0.0	3953	13.6	10.2	129.1	3.7	68.5	83.77	0.600	0.0832	0.0	2	0
185.00	42.1	0.0	0.60	2.11	2	0	0.0	0.0	0.000	0.000	0.0	4602	36.8	23.5	297.3	3.7	64.6	90.62	0.605	0.0840	0.0	2	0

186.00	42.9	0.0	0.80	2.12	2	0	0.0	0.0	0.000	0.000	0.0	4075	32.7	28.5	276.5	3.6	62.9	90.29	0.612	0.0852	0.0	2	0
187.00	43.5	0.0	0.60	2.14	2	0	0.0	0.0	0.000	0.000	0.0	4134	31.2	24.6	314.3	3.5	54.2	89.79	0.616	0.0861	0.0	2	0
188.00	43.9	0.0	0.40	2.15	2	0	0.0	0.0	0.000	0.000	0.0	4174	25.6	20.4	257.7	3.5	65.5	88.84	0.622	0.0868	0.0	2	0
189.00	43.6	0.0	-0.30	2.16	2	0	0.0	0.0	0.000	0.000	0.0	4155	5.4	4.5	65.7	3.5	69.9	68.58	0.624	0.0869	0.0	2	0
190.00	43.3	1.0	-0.30	2.17	2	0	0.0	0.0	0.000	0.000	0.0	4124	5.5	4.4	64.3	3.5	[illegible]	68.37	0.625	0.0870	0.0	2	0
191.00	43.0	0.0	-0.30	2.18	2	0	0.0	0.0	0.000	0.000	0.0	4097	5.5	4.3	63.6	3.6	70.0	68.14	0.626	0.0871	0.0	2	0
192.00	43.1	0.0	0.10	2.20	2	0	0.0	0.0	0.000	0.000	0.0	4103	16.9	13.2	165.9	3.5	67.6	85.79	0.630	0.0875	0.0	2	0
193.00	43.4	0.0	0.30	2.21	2	0	0.0	0.0	0.000	0.000	0.0	4128	22.7	17.6	223.7	3.5	64.3	88.16	0.634	0.0880	0.0	2	0
194.00	43.9	0.0	0.50	2.22	2	0	0.0	0.0	0.000	0.000	0.0	4172	23.5	22.6	268.1	3.5	64.8	69.36	0.639	0.0888	0.0	2	0
195.00	44.3	1.0	0.40	2.23	2	0	0.0	0.0	0.000	0.000	0.0	4211	25.8	20.7	261.9	3.4	65.4	88.76	0.644	0.0895	0.0	2	0
196.00	44.6	0.0	0.30	2.25	2	0	0.0	0.0	0.000	0.000	0.0	4240	23.0	18.6	235.0	3.4	66.0	88.04	0.648	0.0901	0.0	2	0
197.00	44.9	0.0	0.30	2.26	2	0	0.0	0.0	0.000	0.000	0.0	4268	23.1	18.8	237.8	3.4	65.9	88.06	0.653	0.0907	0.0	2	0
198.00	44.8	0.0	-0.10	2.27	2	0	0.0	0.0	0.000	0.000	0.0	4262	11.7	9.5	123.8	3.4	68.6	81.04	0.655	0.0910	0.0	2	0
199.00	44.4	0.0	-0.40	2.28	2	0	0.0	0.0	0.000	0.000	0.0	4229	3.0	2.4	44.4	3.4	70.4	53.78	0.656	0.0911	0.0	2	0
200.00	43.9	0.0	-0.50	2.30	2	0	0.0	0.0	0.000	0.000	0.0	4182	0.0	0.0	18.1	3.5	71.6	0.73	0.656	0.0911	0.0	2	0
201.00	43.4	1.0	-0.50	2.31	2	0	0.0	0.0	0.000	0.000	0.0	4136	-0.1	-0.1	16.4	3.5	71.0	0.73	0.657	0.0911	0.0	2100	
202.00	43.2	0.0	-0.20	2.32	2	0	0.0	0.0	0.000	0.000	0.0	4114	8.4	6.5	80.8	3.5	69.4	76.30	0.659	0.0913	0.0	2	0
203.00	43.2	0.0	0.00	2.33	2	0	0.0	0.0	0.000	0.000	0.0	4112	14.1	11.0	140.1	3.5	66.2	83.80	0.661	0.0916	0.0	2	0
204.00	43.1	0.0	-0.10	2.34	2	0	0.0	0.0	0.000	0.000	0.0	4165	11.2	8.7	113.6	3.5	68.8	86.87	0.663	0.0918	0.0	2	0
205.00	43.0	0.0	-0.10	2.36	2	0	0.0	0.0	0.000	0.000	0.0	4095	11.1	8.7	113.0	3.6	68.8	80.86	0.666	0.0920	0.0	2	0
206.00	43.0	0.0	0.00	2.37	2	0	0.0	0.0	0.000	0.000	0.0	4093	14.0	10.9	138.6	3.6	68.2	83.80	0.668	0.0923	0.0	2	0
207.00	43.1	0.0	0.10	2.38	2	0	0.0	0.0	0.000	0.000	0.0	4103	16.9	13.2	166.0	3.5	67.6	85.79	0.672	0.0927	0.0	2	0
208.00	43.4	0.0	0.30	2.39	2	0	0.0	0.0	0.000	0.000	0.0	4128	22.7	17.8	223.8	3.5	66.2	88.18	0.676	0.0933	0.0	2	0
209.00	43.9	0.0	0.50	2.40	2	0	0.0	0.0	0.000	0.000	0.0	4172	28.5	22.6	260.3	3.5	64.8	89.36	0.681	0.0941	0.0	2	0
210.00	44.0	0.0	0.10	2.42	2	0	0.0	0.0	0.000	0.000	0.0	4186	17.1	13.7	172.8	3.5	67.4	85.75	0.684	0.0945	0.0	2	0
211.00	43.5	0.0	-0.50	2.43	2	0	0.0	0.0	0.000	0.000	0.0	4145	-0.1	-0.1	16.7	3.5	71.0	85.75	0.685	0.0945	0.0	2100	
212.00	42.6	0.0	-0.90	2.44	2	0	0.0	0.0	0.000	0.000	0.0	4066	-11.7	-9.1	-75.9	3.6	73.1	85.75	0.683	0.0944	0.0	2100	
213.00	41.5	0.0	-1.10	2.45	2	0	0.0	0.0	0.000	0.000	0.0	3967	-17.7	-13.4	-118.4	3.7	74.1	85.75	0.681	0.0942	0.0	2100	
214.00	40.7	0.0	-0.80	2.46	2	0	0.0	0.0	0.000	0.000	0.0	3889	-9.4	-7.0	-56.4	3.8	72.7	85.75	0.680	0.0941	0.0	2100	
215.00	40.0	0.0	-0.70	2.47	2	0	0.0	0.0	0.000	0.000	0.0	3821	-6.7	-4.9	-36.2	3.9	72.2	85.75	0.679	0.0941	0.0	2100	
216.00	40.0	0.0	0.00	2.49	2	0	0.0	0.0	0.000	0.000	0.0	3814	13.2	9.6	120.3	3.9	68.6	83.70	0.682	0.0943	0.0	2	0
217.00	40.3	0.0	0.30	2.50	2	0	0.0	0.0	0.000	0.000	0.0	3837	21.8	15.9	196.8	3.8	66.8	88.47	0.685	0.0948	0.0	2	0
218.00	41.0	0.0	0.70	2.51	2	0	0.0	0.0	0.000	0.000	0.0	3897	33.3	24.7	314.2	3.6	64.1	90.46	0.691	0.0957	0.0	2	0
219.00	42.0	0.0	1.00	2.52	2	0	0.0	0.0	0.000	0.000	0.0	3988	42.2	32.0	424.5	3.7	61.6	90.52	0.698	0.0971	0.0	2	0
220.00	42.7	0.0	0.70	2.53	2	0	0.0	0.0	0.000	0.000	0.0	4058	33.8	26.1	336.2	3.6	63.6	96.17	0.704	0.0981	0.0	2	0
221.00	43.1	0.0	0.40	2.54	2	0	0.0	0.0	0.000	0.000	0.0	4099	25.4	19.8	249.9	3.5	65.6	88.94	0.709	0.0988	0.0	2	0
222.00	43.2	0.0	0.10	2.55	2	0	0.0	0.0	0.000	0.000	0.0	4110	16.9	13.2	166.8	3.5	67.5	85.79	0.712	0.0991	0.0	2	0
223.00	43.4	0.0	0.20	2.57	2	0	0.0	0.0	0.000	0.000	0.0	4150	19.8	15.6	195.8	3.5	66.8	87.17	0.716	0.0996	0.0	2	0
224.00	43.9	0.0	0.30	2.58	2	0	0.0	0.0	0.000	0.000	0.0	4172	26.5	22.6	268.5	3.5	64.7	89.35	0.721	0.1004	0.0	2	0
225.00	44.5	0.0	0.40	2.59	2	0	0.0	0.0	0.000	0.000	0.0	4211	25.6	20.7	262.3	3.4	65.3	88.78	0.726	0.1011	0.0	2	0
226.00	44.7	0.0	0.40	2.60	2	0	0.0	0.0	0.000	0.000	0.0	4249	25.9	20.9	266.5	3.4	65.2	88.73	0.731	0.1018	0.0	2	0
227.00	45.1	0.0	0.40	2.62	2	0	0.0	0.0	0.000	0.000	0.0	4267	26.0	21.2	270.9	3.4	65.1	88.66	0.736	0.1026	0.0	2	0
228.00	45.4	0.0	0.30	2.63	2	0	0.0	0.0	0.000	0.000	0.0	4314	23.3	19.1	243.1	3.3	65.7	87.94	0.740	0.1032	0.0	2	0
229.00	45.8	0.0	0.40	2.64	2	0	0.0	0.0	0.000	0.000	0.0	4351	24.2	21.7	278.5	3.3	64.9	88.56	0.745	0.1040	0.0	2	0
230.00	46.5	0.0	0.70	2.65	2	0	0.0	0.0	0.000	0.000	0.0	4415	35.0	29.4	390.4	3.3	62.1	89.40	0.752	0.1052	0.0	2	0
231.00	46.9	0.0	0.40	2.67	2	0	0.0	0.0	0.000	0.000	0.0	4454	26.6	22.5	291.0	3.2	64.6	88.39	0.757	0.1060	0.0	2	0
232.00	47.2	0.0	0.30	2.68	2	0	0.0	0.0	0.000	0.000	0.0	4483	23.8	20.3	261.6	3.2	65.3	87.69	0.762	0.1067	0.0	2	0
233.00	47.4	0.0	0.20	2.69	2	0	0.0	0.0	0.000	0.000	0.0	4502	21.0	18.0	231.7	3.2	66.0	86.76	0.764	0.1073	0.0	2	0
234.00	47.3	0.0	-0.10	2.71	2	0	0.0	0.0	0.000	0.000	0.0	4494	12.4	10.6	140.5	3.2	68.1	81.20	0.769	0.1076	0.0	2	0
235.00	47.3	0.0	0.60	2.72	2	0	0.0	0.0	0.000	0.000	0.0	4494	15.3	13.1	169.8	3.2	67.4	85.75	0.772	0.1080	0.0	2	0
236.00	47.2	0.0	-0.10	2.73	2	0	0.0	0.0	0.000	0.000	0.0	4487	12.4	10.6	139.9	3.2	68.1	81.19	0.775	0.1083	0.0	2	0
237.00	47.2	0.0	0.00	2.75	2	0	0.0	0.0	0.000	0.000	0.0	4485	15.3	13.0	169.0	3.2	67.4	83.75	0.778	0.1087	0.0	2	0
238.00	47.2	0.0	0.00	2.76	2	0	0.0	0.0	0.000	0.000	0.0	4485	15.3	13.0	169.0	3.2	67.4	83.75	0.782	0.1090	0.0	2	0
239.00	47.1	0.0	-0.10	2.77	2	0	0.0	0.0	0.000	0.000	0.0	4477	12.4	10.6	139.2	3.2	68.1	81.18	0.784	0.1093	0.0	2	0
240.00	47.0	0.0	-0.10	2.79	2	0	0.0	0.0	0.000	0.000	0.0	4467	12.3	10.5	136.5	3.2	68.1	81.18	0.787	0.1096	0.0	2	0
241.00	47.0	0.0	0.00	2.80	2	0	0.0	0.0	0.000	0.000	0.0	4467	15.2	12.9	167.5	3.2	67.4	83.76	0.790	0.1100	0.0	2	0
242.00	46.9	0.0	-0.10	2.81	2	0	0.0	0.0	0.000	0.000	0.0	4458	12.3	10.5	137.8	3.2	68.1	81.17	0.793	0.1103	0.0	2	0
243.00	46.8	0.0	-0.10	2.82	2	0	0.0	0.0	0.000	0.000	0.0	4448	12.3	10.4	117.1	3.2	68.1	81.17	0.795	0.1106	0.0	2	0
244.00	46.9	0.0	0.10	2.84	2	0	0.0	0.0	0.000	0.000	0.0	4452	18.0	15.3	196.4	3.2	66.8	85.55	0.799	0.1111	0.0	2	0
245.00	47.0	0.0	0.10	2.85	2	0	0.0	0.0	0.000	0.000	0.0	4465	18.1	15.3	197.3	3.2	66.7	85.54	0.803	0.1115	0.0	2	0
246.00	47.2	0.0	0.20	2.86	2	0	0.0	0.0	0.000	0.000	0.0	4485	21.0	17.9	230.0	3.2	66.6	86.78	0.807	0.1121	0.0	2	0
247.00	47.5	0.0	0.30	2.88	2	0	0.0	0.0	0.000	0.000	0.0	4512	23.9	20.5	265.1	3.2	65.2	87.44	0.812	0.1128	0.0	2	0
248.00	47.9	0.0	0.40	2.89	2	0	0.0	0.0	0.000	0.000	0.0	4547	26.9	23.3	303.0	3.1	64.5	88.21	0.818	0.1137	0.0	2	0

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249.00	48.0	0.0	0.10	2.90	2	0	0.0	0.0	0.000	0.000	0.0	4559	16.4	15.5	206.1	3.1	66.5	85.45	0.821	0.1142	0.0	2	0
250.00	48.0	0.0	0.00	2.92	2	0	0.0	0.0	0.000	0.000	0.0	4520	15.5	13.5	175.4	3.1	67.2	83.72	0.825	0.1146	0.0	2	0
251.00	48.0	0.0	0.00	2.93	2	0	0.0	0.0	0.000	0.000	0.0	4560	15.5	13.5	175.4	3.1	67.2	83.72	0.828	0.1150	0.0	2	0
252.00	48.0	0.0	0.00	2.94	2	0	0.0	0.0	0.000	0.000	0.0	4560	15.5	13.5	175.5	3.1	67.2	83.72	0.831	0.1154	0.0	2	0
253.00	48.0	0.0	0.00	2.96	2	0	0.0	0.0	0.000	0.000	0.0	4560	15.5	13.5	175.5	3.1	67.2	83.72	0.835	0.1158	0.0	2	0
254.00	48.1	0.0	0.10	2.97	2	0	0.0	0.0	0.000	0.000	0.0	4568	18.4	16.6	207.6	3.1	66.5	85.44	0.839	0.1163	0.0	2	0
255.00	48.2	0.0	0.10	2.98	2	0	0.0	0.0	0.000	0.000	0.0	4574	18.4	16.1	208.0	3.1	66.5	85.43	0.842	0.1168	0.0	2	0
256.00	48.2	0.0	0.00	3.00	2	0	0.0	0.0	0.000	0.000	0.0	4572	15.6	13.6	177.0	3.1	67.2	83.71	0.846	0.1172	0.0	2	0
257.00	48.1	0.0	-0.10	3.01	2	0	0.0	0.0	0.000	0.000	0.0	4570	12.7	11.0	146.4	3.1	67.9	81.25	0.849	0.1175	0.0	2	0
258.00	48.6	0.0	0.50	3.02	2	0	0.0	0.0	0.000	0.000	0.0	4613	36.0	26.3	347.8	3.1	63.2	88.51	0.855	0.1186	0.0	2	0
259.00	48.7	0.0	0.30	3.04	2	0	0.0	0.0	0.000	0.000	0.0	4642	24.4	21.5	280.4	3.1	64.8	87.42	0.860	0.1194	0.0	2	0
260.00	49.1	0.0	0.20	3.05	2	0	0.0	0.0	0.000	0.000	0.0	4661	21.6	19.2	249.1	3.1	65.5	86.54	0.865	0.1200	0.0	2	0
261.00	49.1	0.0	0.00	3.06	2	0	0.0	0.0	0.000	0.000	0.0	4661	15.9	14.1	184.5	3.1	67.0	83.67	0.868	0.1205	0.0	2	0
262.00	49.1	0.0	0.00	3.08	2	0	0.0	0.0	0.000	0.000	0.0	4661	15.9	14.1	184.5	3.1	67.0	83.67	0.871	0.1209	0.0	2	0
263.00	49.1	0.0	0.00	3.09	2	0	0.0	0.0	0.000	0.000	0.0	4661	15.9	14.1	184.5	3.1	67.0	83.67	0.875	0.1213	0.0	2	0
264.00	49.1	0.0	0.00	3.10	2	0	0.0	0.0	0.000	0.000	0.0	4661	15.9	14.1	184.5	3.1	67.0	83.67	0.878	0.1217	0.0	2	0
265.00	49.0	0.0	-0.10	3.12	2	0	0.0	0.0	0.000	0.000	0.0	4654	13.0	11.5	153.6	3.1	67.7	81.26	0.881	0.1221	0.0	2	0
266.00	48.9	0.0	-0.10	3.13	2	0	0.0	0.0	0.000	0.000	0.0	4644	13.0	11.5	152.2	3.1	67.7	81.26	0.884	0.1224	0.0	2	0
267.00	48.2	0.0	-0.70	3.15	2	0	0.0	0.0	0.000	0.000	0.0	4582	-4.4	-3.8	-17.9	3.1	71.6	81.26	0.884	0.1224	0.0	2100	
268.00	47.7	0.0	-0.50	3.16	2	0	0.0	0.0	0.000	0.000	0.0	4535	1.2	1.0	32.4	3.1	70.5	29.84	0.885	0.1224	0.0	2	0
269.00	47.5	0.0	-0.20	3.17	2	0	0.0	0.0	0.000	0.000	0.0	4516	9.7	8.3	113.5	3.2	68.6	77.36	0.887	0.1227	0.0	2	0
270.00	47.2	0.0	-0.30	3.19	2	0	0.0	0.0	0.000	0.000	0.0	4467	6.7	5.7	83.9	3.2	69.3	78.86	0.889	0.1228	0.0	2	0
271.00	46.7	0.0	-0.50	3.20	2	0	0.0	0.0	0.000	0.000	0.0	4442	0.9	0.7	28.3	3.2	76.6	24.11	0.889	0.1229	0.0	2	0
272.00	46.2	0.0	-0.50	3.21	2	0	0.0	0.0	0.000	0.000	0.0	4396	0.7	0.6	26.4	3.3	76.6	20.63	0.890	0.1229	0.0	2	0
273.00	46.0	0.0	-0.20	3.22	2	0	0.0	0.0	0.000	0.000	0.0	4374	9.2	7.7	104.4	3.3	68.8	77.04	0.892	0.1231	0.0	2	0
274.00	45.8	0.0	-0.20	3.24	2	0	0.0	0.0	0.000	0.000	0.0	4357	9.1	7.6	103.3	3.3	68.8	76.99	0.894	0.1233	0.0	2	0
275.00	45.6	0.0	-0.20	3.25	2	0	0.0	0.0	0.000	0.000	0.0	4337	9.1	7.5	102.1	3.3	68.8	76.94	0.896	0.1235	0.0	2	0
276.00	45.4	0.0	-0.20	3.26	2	0	0.0	0.0	0.000	0.000	0.0	4320	9.0	7.4	101.0	3.3	68.9	76.89	0.898	0.1237	0.0	2	0
277.00	45.2	0.0	-0.20	3.27	2	0	0.0	0.0	0.000	0.000	0.0	4300	8.9	7.3	99.6	3.4	68.9	76.84	0.900	0.1239	0.0	2	0
278.00	45.0	0.0	-0.20	3.29	2	0	0.0	0.0	0.000	0.000	0.0	4283	8.9	7.2	98.8	3.4	68.9	76.79	0.902	0.1241	0.0	2	0
279.00	44.7	0.0	-0.30	3.30	2	0	0.0	0.0	0.000	0.000	0.0	4256	5.9	4.8	71.1	3.4	69.6	69.36	0.903	0.1242	0.0	2	0
280.00	44.5	0.0	-0.20	3.31	2	0	0.0	0.0	0.000	0.000	0.0	4236	8.7	7.0	96.6	3.4	69.0	76.68	0.905	0.1244	0.0	2	0
281.00	44.2	0.0	-0.30	3.32	2	0	0.0	0.0	0.000	0.000	0.0	4209	5.8	4.7	68.8	3.4	69.6	69.02	0.907	0.1245	0.0	2	0
282.00	43.5	0.0	-0.70	3.34	2	0	0.0	0.0	0.000	0.000	0.0	4147	-5.8	-4.6	-36.0	3.5	71.9	69.02	0.906	0.1244	0.0	2100	
283.00	42.8	0.0	-0.70	3.35	2	0	0.0	0.0	0.000	0.000	0.0	4083	-6.0	-4.7	-31.5	3.6	71.9	69.02	0.906	0.1244	0.0	2100	
284.00	42.0	0.0	-0.80	3.36	2	0	0.0	0.0	0.000	0.000	0.0	4009	-9.1	-6.9	-55.0	3.6	72.5	69.02	0.904	0.1243	0.0	2100	
285.00	40.1	0.0	-1.90	3.37	2	0	0.0	0.0	0.000	0.000	0.0	3847	-40.8	-29.9	-268.8	3.8	77.4	69.02	0.899	0.1239	0.0	2100	
286.00	38.6	0.0	-1.50	3.38	2	0	0.0	0.0	0.000	0.000	0.0	3703	-29.8	-21.0	-191.7	4.0	75.6	69.02	0.895	0.1236	0.0	2100	
287.00	37.5	0.0	-1.10	3.39	2	0	0.0	0.0	0.000	0.000	0.0	3594	-18.7	-12.8	-116.0	4.2	73.5	69.02	0.893	0.1235	0.0	2100	
288.00	35.8	0.0	-1.70	3.40	2	0	0.0	0.0	0.000	0.000	0.0	3447	-36.2	-23.7	-217.5	4.4	76.2	69.02	0.889	0.1231	0.0	2100	
289.00	34.7	0.0	-1.10	3.41	2	0	0.0	0.0	0.000	0.000	0.0	3334	-19.4	-12.3	-112.8	4.6	73.8	69.02	0.886	0.1230	0.0	2100	
290.00	34.0	0.0	-0.70	3.42	2	0	0.0	0.0	0.000	0.000	0.0	3263	-8.2	-5.1	-42.2	4.7	72.1	69.02	0.885	0.1229	0.0	2100	
291.00	33.3	0.0	-0.70	3.43	2	0	0.0	0.0	0.000	0.000	0.0	3157	-4.3	-5.1	-42.5	4.8	72.2	69.02	0.884	0.1229	0.0	2100	
292.00	32.5	0.0	-0.80	3.44	2	0	0.0	0.0	0.000	0.000	0.0	3125	-11.3	-6.7	-59.7	4.9	72.5	69.02	0.883	0.1228	0.0	2100	
293.00	31.7	0.0	-0.80	3.45	2	0	0.0	0.0	0.000	0.000	0.0	3049	-11.5	-6.7	-59.5	5.1	72.5	69.02	0.882	0.1227	0.0	2100	
294.00	30.6	0.0	-1.10	3.46	2	0	0.0	0.0	0.000	0.000	0.0	2952	-26.2	-11.4	-106.1	5.3	73.6	69.02	0.880	0.1226	0.0	2100	
295.00	29.6	0.0	-1.00	3.47	2	0	0.0	0.0	0.000	0.000	0.0	2857	-17.6	-9.6	-89.1	5.5	73.2	69.02	0.878	0.1224	0.0	2100	
296.00	28.8	0.0	-0.80	3.48	2	0	0.0	0.0	0.000	0.000	0.0	2778	-12.1	-6.4	-58.6	5.8	72.5	69.02	0.877	0.1223	0.0	2100	
297.00	28.4	0.0	0.40	3.48	2	0	0.0	0.0	0.000	0.000	0.0	2731	-0.8	-0.4	2.8	5.9	71.1	69.02	0.877	0.1223	0.0	2100	
298.00	28.8	0.0	0.40	3.49	2	0	0.0	0.0	0.000	0.000	0.0	2737	14.2	8.4	59.9	5.9	68.8	86.44	0.879	0.1225	0.0	2	0
299.00	29.5	0.0	0.90	3.50	2	0	0.0	0.0	0.000	0.000	0.0	2805	36.2	19.3	232.6	5.7	65.8	91.76	0.884	0.1231	0.0	2	0
300.00	31.3	0.1	1.75	3.51	2	0	0.0	0.0	0.000	0.000	0.0	2954	60.7	34.1	449.9	5.3	60.8	92.64	0.892	0.1247	0.0	2311	
301.00	33.4	0.0	2.15	3.52	2	3150	87.6	52.6	24.962	0.475	9.1	3150	-13.2	-7.9	9.7	4.9	76.9	*******	0.892	0.1247	0.0	3	0
302.00	35.6	0.0	2.20	3.53	2	3362	87.1	55.7	26.749	0.478	9.1	3362	-10.6	-6.8	11.1	4.5	76.9	*******	0.892	0.1247	0.0	3	0
303.00	37.5	0.0	1.90	3.54	2	3546	86.3	58.3	28.065	0.481	9.2	3548	-18.1	-12.2	12.5	4.2	76.9	*******	0.892	0.1247	0.0	3	0
304.00	39.1	0.0	1.20	3.55	2	3705	84.9	59.9	28.966	0.483	9.3	3705	-25.1	-17.7	13.7	4.0	70.9	*******	0.893	0.1247	0.0	3	0
305.00	40.2	0.0	1.10	3.56	2	0	0.0	0.0	0.000	0.000	9.3	3817	45.5	33.1	441.5	3.9	61.0	90.80	0.906	0.1266	0.0	2	0
306.00	41.1	0.0	0.90	3.57	2	0	0.0	0.0	0.000	0.000	9.3	3905	39.1	29.0	378.9	3.8	62.4	90.68	0.907	0.1274	0.0	2	0
307.00	41.8	0.0	0.70	3.58	2	0	0.0	0.0	0.000	0.000	9.3	3973	33.6	25.4	325.9	3.7	63.4	90.36	0.913	0.1284	0.0	2	0
308.00	42.4	0.0	0.60	3.59	2	0	0.0	0.0	0.000	0.000	9.3	4031	30.9	23.7	302.9	3.6	64.2	89.96	0.918	0.1292	0.0	2	0
309.00	42.8	0.0	0.40	3.60	2	0	0.0	0.0	0.000	0.000	9.3	4072	25.3	19.6	248.0	3.6	65.4	88.97	0.923	0.1299	0.0	2	0
310.00	43.3	0.0	0.50	3.62	2	0	0.0	0.0	0.000	0.000	9.3	4116	26.3	22.2	282.9	3.5	64.6	89.43	0.928	0.1307	0.0	2	0
311.00	43.8	0.0	0.50	3.63	2	0	0.0	0.0	0.000	0.000	9.3	4163	28.5	22.6	285.6	3.5	64.5	89.35	0.933	0.1315	0.0	2	0

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312.00	44.3	0.0	0.50	3.64	2	0	0.0	0.0	0.000	0.000	9.3	4209	26.6	22.9	294.3	3.4	64.3	89.27	0.939	0.1323	0.0	2	0
313.00	44.7	0.0	0.40	3.65	2	0	0.0	0.0	0.000	0.000	9.3	4246	25.9	20.9	267.6	3.4	65.6	88.71	0.943	0.1330	0.0	2	0
314.00	45.0	0.0	0.30	3.67	2	0	0.0	0.0	0.000	0.000	9.3	4277	23.1	18.8	246.1	3.4	65.6	87.97	0.948	0.1336	0.0	2	0
315.00	45.4	0.0	0.40	3.68	2	0	0.0	0.0	0.000	0.000	9.3	4314	26.1	21.4	275.3	3.3	64.8	88.61	0.953	0.1344	0.0	2	0
316.00	45.6	0.0	0.00	3.69	2	0	0.0	0.0	0.000	0.000	9.3	4318	14.7	12.1	156.6	3.3	67.5	85.79	0.956	0.1347	0.0	2	0
317.00	45.5	0.0	0.10	3.70	2	0	0.0	0.0	0.000	0.000	9.3	4326	17.6	14.5	185.5	3.3	66.7	85.65	0.959	0.1352	0.0	2	0
318.00	45.8	0.0	0.30	3.72	2	0	0.0	0.0	0.000	0.000	9.3	4353	23.4	19.4	246.2	3.3	65.4	87.07	0.964	0.1358	0.0	2	0
319.00	46.0	0.0	0.20	3.73	2	0	0.0	0.0	0.000	0.000	9.3	4372	21.6	17.1	219.4	3.3	66.0	86.91	0.968	0.1364	0.0	2	0
320.00	46.1	0.0	0.10	3.74	2	0	0.0	0.0	0.000	0.000	9.3	4382	17.8	14.2	190.3	3.3	66.7	85.80	0.972	0.1368	0.0	2	0
321.00	46.5	0.0	0.40	3.75	2	0	0.0	0.0	0.000	0.000	9.3	4417	26.6	22.2	282.7	3.2	64.5	88.43	0.977	0.1376	0.0	2	0
322.00	46.8	0.0	0.30	3.77	2	0	0.0	0.0	0.000	0.000	9.3	4446	23.7	20.1	258.5	3.2	65.1	87.73	0.982	0.1383	0.0	2	0
323.00	47.1	0.0	0.30	3.78	2	0	0.0	0.0	0.000	0.000	9.3	4473	23.8	20.3	261.6	3.2	65.0	87.69	0.986	0.1390	0.0	2	0
324.00	47.7	0.0	0.60	3.79	2	0	0.0	0.0	0.000	0.000	9.3	4527	32.5	28.0	373.3	3.2	62.5	88.95	0.993	0.1402	0.0	2	0
325.00	48.3	0.0	0.60	3.81	2	0	0.0	0.0	0.000	0.000	9.3	4586	32.7	28.6	382.2	3.1	62.2	88.81	1.000	0.1414	0.0	2	0
326.00	49.0	0.0	0.70	3.82	2	0	0.0	0.0	0.000	0.000	9.3	4662	35.8	31.7	433.0	3.1	61.1	86.77	1.007	0.1428	0.0	2	0
327.00	49.7	0.0	0.70	3.83	2	0	0.0	0.0	0.000	0.000	9.3	4714	36.0	32.4	445.3	3.0	60.8	86.59	1.014	0.1443	0.0	2	0
328.00	50.3	0.0	0.60	3.85	2	0	0.0	0.0	0.000	0.000	9.3	4770	33.4	30.3	413.5	3.0	61.5	86.35	1.022	0.1456	0.0	2	0
329.00	51.0	0.0	0.66	3.86	2	0	0.0	0.0	0.000	0.000	9.3	4832	35.3	32.5	449.6	2.9	60.6	86.24	1.029	0.1471	0.0	2316	
330.00	51.7	0.0	0.74	3.88	2	4906	70.4	65.7	35.362	0.542	10.2	4966	-31.8	-29.7	26.1	2.9	70.5*******		1.030	0.1472	0.0	3	0
331.00	51.9	0.5	0.96	3.89	3	3158	87.6	26.3	15.484	0.475	14.6	3158	-19.6	-5.1	21.6	4.2	70.8*******		1.030	0.1472	0.0	3	1
332.00	53.1	0.0	1.21	3.91	3	3215	87.4	53.5	25.490	0.476	14.5	3215	-4.8	-4.2	10.1	4.8	70.8*******		1.030	0.1472	0.0	3	0
333.00	53.6	0.0	0.70	3.92	3	3258	87.3	54.2	25.631	0.477	14.6	3258	-29.2	-18.1	10.4	4.7	70.8*******		1.031	0.1473	0.0	3	0
334.00	54.5	0.0	0.70	3.94	3	3299	87.2	54.8	26.154	0.477	14.6	3299	-28.7	-18.0	16.7	4.6	70.8*******		1.031	0.1475	0.0	3	0
335.00	55.2	0.0	0.70	3.95	3	3341	87.1	55.4	26.468	0.476	14.6	3341	-28.2	-17.9	11.6	4.5	70.8*******		1.031	0.1475	0.0	3	0
336.00	55.8	0.0	0.60	3.97	3	3377	87.0	56.0	26.774	0.474	14.6	3377	-32.2	-20.7	11.2	4.5	70.8*******		1.031	0.1473	0.0	3	0
337.00	56.4	0.0	0.60	3.98	3	3412	86.9	56.5	27.058	0.479	14.6	3412	-31.7	-20.4	11.5	4.4	70.8*******		1.032	0.1473	0.0	3	0
338.00	56.9	0.0	0.50	4.00	3	0	0.0	0.0	0.000	0.000	14.6	3442	51.0	33.4	445.1	4.4	60.7	91.42	1.039	0.1488	0.0	2	0
339.00	57.0	0.0	0.10	4.01	3	0	0.0	0.0	0.000	0.000	14.6	3448	33.2	21.8	271.2	4.4	64.7	91.18	1.044	0.1496	0.0	2	0
340.00	57.1	0.0	0.10	4.03	3	0	0.0	0.0	0.000	0.000	14.6	3454	33.3	21.9	272.4	4.4	64.7	91.16	1.049	0.1505	0.0	2	0
341.00	57.3	0.0	0.20	4.04	3	0	0.0	0.0	0.000	0.000	14.6	3465	37.8	24.9	314.9	4.3	63.7	91.46	1.055	0.1512	0.0	2	0
342.00	57.6	0.0	0.30	4.06	3	0	0.0	0.0	0.000	0.000	14.6	3484	42.4	28.1	361.5	4.3	62.6	91.52	1.061	0.1523	0.0	2	0
343.00	57.8	0.0	0.20	4.08	3	0	0.0	0.0	0.000	0.000	14.6	3495	38.1	25.3	321.2	4.3	63.5	91.40	1.067	0.1533	0.0	2	0
344.00	58.0	0.0	0.20	4.09	3	0	0.0	0.0	0.000	0.000	14.6	3507	38.2	25.5	323.8	4.3	63.5	91.39	1.073	0.1542	0.0	2	0
345.00	58.1	0.0	0.10	4.11	3	0	0.0	0.0	0.000	0.000	14.6	3512	33.9	22.7	283.6	4.3	64.4	91.12	1.078	0.1550	0.0	2	0
346.00	58.4	0.0	0.30	4.13	3	0	0.0	0.0	0.000	0.000	14.6	3531	42.9	28.8	372.9	4.2	62.3	91.43	1.084	0.1562	0.0	2	0
347.00	58.7	0.0	0.30	4.14	3	0	0.0	0.0	0.000	0.000	14.6	3548	43.0	29.1	377.2	4.2	62.2	91.39	1.091	0.1574	0.0	2	0
348.00	58.8	0.0	0.10	4.16	3	0	0.0	0.0	0.000	0.000	14.6	3555	34.3	23.2	291.9	4.2	64.2	91.09	1.096	0.1582	0.0	2	0
349.00	58.9	0.0	0.10	4.17	3	0	0.0	0.0	0.000	0.000	14.6	3560	34.4	23.3	293.6	4.2	64.1	91.09	1.102	0.1590	0.0	2	0
350.00	59.0	0.0	0.10	4.19	3	0	0.0	0.0	0.000	0.000	14.6	3566	34.4	23.4	294.2	4.2	64.1	91.08	1.107	0.1599	0.0	2	0
351.00	59.0	0.0	0.03	4.21	3	0	0.0	0.0	0.000	0.000	14.6	3564	30.0	20.4	253.5	4.2	65.1	90.64	1.112	0.1605	0.0	2	0
352.00	58.9	0.0	-0.10	4.22	3	0	0.0	0.0	0.000	0.000	14.6	3560	25.6	17.3	213.6	4.2	66.0	89.89	1.116	0.1610	0.0	2	0
353.00	58.8	0.0	-0.10	4.24	3	0	0.0	0.0	0.000	0.000	14.6	3553	25.5	17.2	212.6	4.2	66.0	89.88	1.120	0.1616	0.0	2	0
354.00	58.6	0.0	-0.20	4.26	3	0	0.0	0.0	0.000	0.000	14.6	3542	21.6	14.1	173.6	4.2	66.9	88.66	1.123	0.1620	0.0	2	0
355.00	58.4	0.0	-0.20	4.27	3	0	0.0	0.0	0.000	0.000	14.6	3530	20.8	14.0	171.9	4.2	66.9	88.61	1.126	0.1624	0.0	2	0
356.00	58.2	0.0	-0.20	4.29	3	0	0.0	0.0	0.000	0.000	14.6	3519	20.7	13.9	170.3	4.3	67.0	88.58	1.129	0.1628	0.0	2	0
357.00	58.1	0.0	-0.10	4.30	3	0	0.0	0.0	0.000	0.000	14.6	3512	25.1	16.8	206.2	4.3	66.1	89.84	1.133	0.1633	0.0	2	0
358.00	58.0	0.0	-0.10	4.32	3	0	0.0	0.0	0.000	0.000	14.6	3506	25.0	16.7	205.2	4.3	66.2	89.83	1.137	0.1638	0.0	2	0
359.00	57.9	0.0	-0.10	4.34	3	0	0.0	0.0	0.000	0.000	14.6	3501	24.9	16.6	204.4	4.3	66.2	89.83	1.141	0.1643	0.0	2	0
360.00	57.6	0.0	-0.33	4.35	3	0	0.0	0.0	0.000	0.000	14.6	3467	16.0	10.6	130.6	4.3	67.9	86.35	1.144	0.1645	0.0	2	0
361.00	57.4	0.0	-0.20	4.37	3	0	0.0	0.0	0.000	0.000	14.6	3472	20.3	13.4	163.8	4.3	67.1	88.46	1.147	0.1649	0.0	2	0
362.00	57.2	0.0	-0.20	4.38	3	0	0.0	0.0	0.000	0.000	14.6	3459	20.1	13.3	162.2	4.4	67.1	88.43	1.150	0.1653	0.0	2	0
363.00	57.1	0.0	-0.10	4.40	3	0	0.0	0.0	0.000	0.000	14.6	3453	24.5	16.1	197.2	4.4	66.3	89.77	1.153	0.1658	0.0	2	0
364.00	57.0	0.0	-0.10	4.42	3	0	0.0	0.0	0.000	0.000	14.6	3445	24.4	16.0	196.4	4.4	66.3	89.76	1.157	0.1662	0.0	2	0
365.00	57.0	0.0	0.00	4.43	3	0	0.0	0.0	0.000	0.000	14.6	3449	28.8	18.9	233.4	4.4	65.5	90.62	1.161	0.1668	0.0	2	0
366.00	56.9	0.0	-0.10	4.45	3	0	0.0	0.0	0.000	0.000	14.6	3442	24.4	16.0	195.5	4.4	66.4	89.76	1.165	0.1673	0.0	2	0
367.00	56.9	0.0	0.00	4.46	3	0	0.0	0.0	0.000	0.000	14.6	3442	28.8	18.8	232.4	4.4	65.5	90.62	1.169	0.1679	0.0	2	0
368.00	56.9	0.0	0.00	4.48	3	0	0.0	0.0	0.000	0.000	14.6	3442	28.8	18.8	232.4	4.4	65.5	90.62	1.174	0.1685	0.0	2	0
369.00	57.0	0.0	0.10	4.50	3	0	0.0	0.0	0.000	0.000	14.6	3448	33.2	21.8	272.0	4.4	64.6	91.15	1.179	0.1692	0.0	2	0
370.00	57.0	0.0	0.00	4.51	3	0	0.0	0.0	0.000	0.000	14.6	3448	28.8	18.9	233.5	4.4	65.5	90.62	1.183	0.1698	0.0	2	0
371.00	57.0	0.0	0.00	4.53	3	0	0.0	0.0	0.000	0.000	14.6	3448	28.8	18.9	233.5	4.4	65.4	90.62	1.187	0.1704	0.0	2	0
372.00	57.0	0.0	0.00	4.54	3	0	0.0	0.0	0.000	0.000	14.6	3448	28.8	18.9	233.5	4.4	65.4	90.62	1.192	0.1710	0.0	2	0
373.00	57.0	0.0	0.00	4.56	3	0	0.0	0.0	0.000	0.000	14.6	3448	28.8	18.9	233.5	4.4	65.4	90.62	1.196	0.1716	0.0	2	0
374.00	57.0	0.0	0.00	4.57	3	0	0.0	0.0	0.000	0.000	14.6	3448	28.8	18.9	233.5	4.4	65.4	90.62	1.200	0.1722	0.0	2	0

375.00	57.0	0.0	0.00	4.59	3	0	0.0	0.0	0.000	0.000	14.6	3448	28.8	18.9	233.6	4.4	65.4	90.62	1.205	0.1728	0.0	2	0
376.00	57.0	0.0	0.00	4.61	3	0	0.0	0.0	0.000	0.000	14.6	3448	28.8	18.9	233.6	4.4	65.4	90.62	1.209	0.1734	0.0	2	0
377.00	57.0	0.0	0.00	4.62	3	0	0.0	0.0	0.000	0.000	14.6	3448	28.8	18.9	233.6	4.4	65.4	90.62	1.213	0.1740	0.0	2	0
378.00	56.9	0.0	-0.10	4.64	3	0	0.0	0.0	0.000	0.000	14.6	3442	24.4	16.0	195.7	4.4	66.3	89.75	1.217	0.1745	0.0	2	0
379.00	56.8	0.0	-0.10	4.65	3	0	0.0	0.0	0.000	0.000	14.6	3436	24.3	15.9	194.6	4.4	66.3	89.75	1.221	0.1750	0.0	2	0
380.00	56.5	0.0	-0.30	4.67	3	0	0.0	0.0	0.000	0.000	14.6	3418	15.3	10.0	122.8	4.4	68.0	88.00	1.225	0.1752	0.0	2	0
381.00	56.2	0.0	-0.30	4.69	3	0	0.0	0.0	0.000	0.000	14.6	3401	15.2	9.8	120.7	4.4	68.0	85.90	1.225	0.1755	0.0	2	0
382.00	56.0	0.0	-0.20	4.70	3	0	0.0	0.0	0.000	0.000	14.6	3388	19.4	12.5	153.1	4.5	67.3	88.22	1.228	0.1758	0.0	2	0
383.00	56.0	0.0	0.00	4.72	3	0	0.0	0.0	0.000	0.000	14.6	3388	28.2	18.2	224.0	4.5	65.6	90.60	1.233	0.1764	0.0	2	0
384.00	56.0	0.0	0.00	4.73	3	0	0.0	0.0	0.000	0.000	14.6	3388	28.2	18.2	224.0	4.5	65.6	90.60	1.237	0.1770	0.0	2	0
385.00	56.1	0.0	0.10	4.75	3	0	0.0	0.0	0.000	0.000	14.6	3395	32.7	21.1	262.6	4.5	64.7	91.17	1.242	0.1777	0.0	2	0
386.00	56.4	0.0	0.30	4.76	3	0	0.0	0.0	0.000	0.000	14.6	3412	41.7	27.1	346.7	4.4	62.7	91.61	1.248	0.1787	0.0	2	0
387.00	56.7	0.0	0.30	4.78	3	0	0.0	0.0	0.000	0.000	14.6	3431	41.6	27.3	350.9	4.4	62.6	91.58	1.254	0.1798	0.0	2	0
388.00	56.9	0.0	0.20	4.79	3	0	0.0	0.0	0.000	0.000	14.6	3442	37.6	24.6	311.4	4.4	63.5	91.45	1.259	0.1807	0.0	2	0
389.00	57.1	0.0	0.20	4.81	3	0	0.0	0.0	0.000	0.000	14.6	3454	37.7	24.8	314.0	4.4	63.5	91.43	1.265	0.1816	0.0	2	0
390.00	57.3	0.0	0.20	4.83	3	0	0.0	0.0	0.000	0.000	14.6	3465	37.8	24.9	316.4	4.3	63.4	91.42	1.271	0.1825	0.0	2	0
391.00	57.4	0.0	0.10	4.84	3	0	0.0	0.0	0.000	0.000	14.6	3472	33.4	22.1	276.9	4.3	64.3	91.13	1.276	0.1833	0.0	2	0
392.00	57.4	0.0	0.00	4.86	3	0	0.0	0.0	0.000	0.000	14.6	3472	29.1	19.2	237.9	4.3	65.2	90.62	1.280	0.1839	0.0	2	0
393.00	57.2	0.0	-0.20	4.87	3	0	0.0	0.0	0.000	0.000	14.6	3459	20.1	13.3	162.6	4.4	67.0	88.43	1.283	0.1843	0.0	2	0
394.00	57.0	0.0	-0.20	4.89	3	0	0.0	0.0	0.000	0.000	14.6	3448	20.0	13.1	161.0	4.4	67.0	88.39	1.286	0.1846	0.0	2	0
395.00	56.9	0.0	-0.10	4.91	3	0	0.0	0.0	0.000	0.000	14.6	3442	24.4	16.0	195.9	4.4	66.2	89.75	1.290	0.1851	0.0	2	0
396.00	56.6	0.0	-0.30	4.92	3	0	0.0	0.0	0.000	0.000	14.6	3424	15.4	10.0	123.6	4.4	67.9	86.04	1.292	0.1854	0.0	2	0
397.00	56.3	0.0	-0.30	4.94	3	0	0.0	0.0	0.000	0.000	14.6	3406	15.2	9.9	121.5	4.4	68.0	85.94	1.295	0.1856	0.0	2	0
398.00	56.1	0.0	-0.20	4.95	3	0	0.0	0.0	0.000	0.000	14.6	3395	19.5	12.6	154.0	4.5	67.2	88.24	1.298	0.1859	0.0	2	0
399.00	56.4	0.0	0.30	4.97	3	0	0.0	0.0	0.000	0.000	14.6	3412	41.7	27.1	347.2	4.4	62.7	91.61	1.304	0.1870	0.0	2	0
400.00	56.7	0.0	0.30	4.98	3	0	0.0	0.0	0.000	0.000	14.6	3431	41.8	27.3	351.3	4.4	62.6	91.56	1.310	0.1881	0.0	2	0
401.00	57.1	0.0	0.40	5.00	3	0	0.0	0.0	0.000	0.000	14.6	3454	46.5	30.6	401.5	4.4	61.4	91.50	1.317	0.1894	0.0	2	0
402.00	57.5	0.0	0.40	5.02	3	0	0.0	0.0	0.000	0.000	14.6	3478	46.7	30.9	407.8	4.3	61.2	91.44	1.324	0.1907	0.0	2	0
403.00	57.8	0.0	0.30	5.03	3	0	0.0	0.0	0.000	0.000	14.6	3495	42.5	28.3	366.6	4.3	62.2	91.46	1.330	0.1916	0.0	2	0
404.00	58.0	0.0	0.20	5.05	3	0	0.0	0.0	0.000	0.000	14.6	3507	38.2	25.5	325.7	4.3	63.1	91.36	1.336	0.1928	0.0	2	0
405.00	58.0	0.0	0.00	5.06	3	0	0.0	0.0	0.000	0.000	14.6	3506	29.4	19.6	244.2	4.3	65.0	90.63	1.341	0.1934	0.0	2	0
406.00	58.0	0.0	0.00	5.08	3	0	0.0	0.0	0.000	0.000	14.6	3506	29.4	19.6	244.2	4.3	65.0	90.63	1.345	0.1940	0.0	2	0
407.00	58.0	0.0	0.00	5.10	3	0	0.0	0.0	0.000	0.000	14.6	3506	29.4	19.6	244.2	4.3	65.0	90.63	1.350	0.1947	0.0	2	0
408.00	58.0	0.0	0.00	5.11	3	0	0.0	0.0	0.000	0.000	14.6	3506	29.4	19.6	244.2	4.3	65.0	90.63	1.354	0.1953	0.0	2	0
409.00	58.0	0.0	0.00	5.13	3	0	0.0	0.0	0.000	0.000	14.6	3506	29.4	19.6	244.3	4.3	65.0	90.63	1.359	0.1960	0.0	2	0
410.00	57.9	0.0	-0.10	5.14	3	0	0.0	0.0	0.000	0.000	14.6	3501	24.9	16.6	205.2	4.3	65.9	89.82	1.362	0.1965	0.0	2	0
411.00	57.8	0.0	-0.10	5.16	3	0	0.0	0.0	0.000	0.000	14.6	3495	24.9	16.6	204.3	4.3	65.9	89.81	1.366	0.1970	0.0	2	0
412.00	57.7	0.0	-0.10	5.18	3	0	0.0	0.0	0.000	0.000	14.6	3489	24.8	16.5	203.4	4.3	66.0	89.81	1.370	0.1975	0.0	2	0
413.00	57.7	0.0	0.00	5.19	3	0	0.0	0.0	0.000	0.000	14.6	3489	29.2	19.4	241.3	4.3	65.1	90.62	1.374	0.1981	0.0	2	0
414.00	57.8	0.0	0.10	5.21	3	0	0.0	0.0	0.000	0.000	14.6	3495	33.7	22.4	282.0	4.3	64.1	91.11	1.380	0.1989	0.0	2	0
415.00	57.9	0.0	0.10	5.22	3	0	0.0	0.0	0.000	0.000	14.6	3501	33.7	22.5	283.2	4.3	64.1	91.11	1.385	0.1997	0.0	2	0
416.00	58.0	0.0	0.10	5.24	3	0	0.0	0.0	0.000	0.000	14.6	3506	33.8	22.6	284.3	4.3	64.0	91.10	1.390	0.2005	0.0	2	0
417.00	58.1	0.0	0.10	5.26	3	0	0.0	0.0	0.000	0.000	14.6	3512	33.9	22.7	285.5	4.3	64.0	91.10	1.395	0.2013	0.0	2	0
418.00	58.4	0.0	0.30	5.27	3	0	0.0	0.0	0.000	0.000	14.6	3531	42.9	28.8	375.8	4.2	61.9	91.38	1.401	0.2024	0.0	2	0
419.00	58.8	0.1	0.44	5.29	3	0	0.0	0.0	0.000	0.000	14.6	3557	49.2	33.3	449.6	4.2	60.1	91.15	1.409	0.2039	0.0	2	310
420.00	59.1	0.0	0.20	5.31	3	0	0.0	0.0	0.000	0.000	14.6	3572	41.6	28.3	386.3	4.2	62.0	91.30	1.415	0.2051	0.0	2	0
421.00	59.4	0.0	0.30	5.32	3	0	0.0	0.0	0.000	0.000	14.6	3589	43.5	29.7	390.7	4.2	61.5	91.26	1.422	0.2063	0.0	2	0
422.00	59.6	0.0	0.40	5.34	3	0	0.0	0.0	0.000	0.000	14.6	3614	46.1	33.1	446.8	4.1	60.1	91.06	1.430	0.2076	0.0	2	0
423.00	59.9	0.0	0.10	5.36	3	0	0.0	0.0	0.000	0.000	14.6	3619	35.0	24.1	307.3	4.1	63.4	91.00	1.435	0.2087	0.0	2	0
424.00	59.9	0.0	0.00	5.37	3	0	0.0	0.0	0.000	0.000	14.6	3619	30.6	21.1	265.0	4.1	64.4	90.61	1.440	0.2094	0.0	2	0
425.00	59.8	0.0	-0.10	5.39	3	0	0.0	0.0	0.000	0.000	14.6	3613	26.1	18.0	223.6	4.1	65.4	89.91	1.444	0.2100	0.0	2	0
426.00	59.6	0.0	-0.20	5.41	3	0	0.0	0.0	0.000	0.000	14.6	3600	21.6	14.8	183.2	4.1	66.3	88.76	1.448	0.2104	0.0	2	0
427.00	59.4	0.0	-0.20	5.42	3	0	0.0	0.0	0.000	0.000	14.6	3589	21.5	14.7	181.5	4.2	66.4	88.73	1.451	0.2109	0.0	2	0
428.00	59.2	0.0	-0.20	5.44	3	0	0.0	0.0	0.000	0.000	14.6	3577	21.3	14.5	179.7	4.2	66.4	88.71	1.454	0.2113	0.0	2	0
429.00	59.1	0.0	-0.10	5.45	3	0	0.0	0.0	0.000	0.000	14.6	3572	25.7	17.5	216.9	4.2	65.5	89.88	1.458	0.2118	0.0	2	0
430.00	59.0	0.0	-0.10	5.47	3	0	0.0	0.0	0.000	0.000	14.6	3566	25.6	17.4	215.9	4.2	65.6	89.88	1.463	0.2124	0.0	2	0
431.00	58.9	0.0	-0.10	5.49	3	0	0.0	0.0	0.000	0.000	14.6	3560	25.6	17.3	215.0	4.2	65.6	89.87	1.466	0.2129	0.0	2	0
432.00	58.7	0.0	-0.20	5.50	3	0	0.0	0.0	0.000	0.000	14.6	3547	21.0	14.2	175.5	4.2	66.5	88.65	1.470	0.2133	0.0	2	0
433.00	58.6	0.0	-0.10	5.52	3	0	0.0	0.0	0.000	0.000	14.6	3542	25.4	17.1	212.1	4.2	65.6	89.86	1.474	0.2138	0.0	2	0
434.00	58.5	0.0	-0.10	5.54	3	0	0.0	0.0	0.000	0.000	14.6	3536	25.3	17.0	211.2	4.2	65.7	89.85	1.478	0.2144	0.0	2	0
435.00	58.4	0.0	-0.10	5.55	3	0	0.0	0.0	0.000	0.000	14.6	3530	25.2	17.0	210.3	4.2	65.7	89.85	1.482	0.2149	0.0	2	0
436.00	58.4	0.0	0.00	5.57	3	0	0.0	0.0	0.000	0.000	14.6	3530	29.6	19.9	249.1	4.2	64.7	90.62	1.486	0.2155	0.0	2	0
437.00	58.3	0.0	-0.10	5.58	3	0	0.0	0.0	0.000	0.000	14.6	3525	25.2	16.9	209.4	4.3	65.7	89.84	1.490	0.2160	0.0	2	0

438.00	58.2	0.0	-0.10	5.60	3	0	0.0	0.0	0.000	0.000	14.6	3519	25.1	16.8	208.5	4.3	65.7	89.83	1.494	0.2176	0.0	2	0
439.00	58.1	0.0	-0.10	5.62	3	0	0.0	0.0	0.000	0.000	14.6	3512	25.1	16.8	207.5	4.3	65.7	89.83	1.498	0.2171	0.0	2	0
440.00	58.0	0.0	-0.10	5.63	3	0	0.0	0.0	0.000	0.000	14.6	3506	25.0	16.7	206.6	4.3	65.7	89.82	1.502	0.2176	0.0	2	0
441.00	57.9	0.0	-0.10	5.65	3	0	0.0	0.0	0.000	0.000	14.6	3501	24.9	16.6	205.8	4.3	65.6	89.82	1.505	0.2181	0.0	2	0
442.00	57.9	0.0	0.00	5.67	3	0	0.0	0.0	0.000	0.000	14.6	3501	29.3	19.6	244.1	4.3	64.8	90.61	1.510	0.2187	0.0	2	0
443.00	57.9	0.0	0.00	5.68	3	0	0.0	0.0	0.000	0.000	14.6	3501	29.3	19.6	244.1	4.3	64.8	90.61	1.514	0.2194	0.0	2	0
444.00	57.9	0.0	0.00	5.70	3	0	0.0	0.0	0.000	0.000	14.6	3501	29.3	19.6	244.1	4.3	64.8	90.61	1.519	0.2200	0.0	2	0
445.00	57.9	0.0	0.00	5.71	3	0	0.0	0.0	0.000	0.000	14.6	3501	29.3	19.6	244.1	4.3	64.8	90.61	1.523	0.2206	0.0	2	0
446.00	58.0	0.0	0.10	5.73	3	0	0.0	0.0	0.000	0.000	14.6	3506	33.8	22.6	285.2	4.3	63.8	91.09	1.529	0.2214	0.0	2	0
447.00	58.1	0.0	0.10	5.75	3	0	0.0	0.0	0.000	0.000	14.6	3512	33.9	22.7	286.4	4.3	63.8	91.09	1.534	0.2222	0.0	2	0
448.00	58.1	0.0	0.00	5.76	3	0	0.0	0.0	0.000	0.000	14.6	3512	29.5	19.7	246.2	4.3	64.8	90.61	1.538	0.2229	0.0	2	0
449.00	58.2	0.0	0.10	5.78	3	0	0.0	0.0	0.000	0.000	14.6	3519	33.9	22.7	287.6	4.3	63.8	91.08	1.543	0.2237	0.0	2	0
450.00	58.2	0.0	0.00	5.79	3	0	0.0	0.0	0.000	0.000	14.6	3519	29.5	19.8	247.3	4.3	64.7	90.61	1.548	0.2243	0.0	2	0
451.00	58.2	0.0	0.00	5.81	3	0	0.0	0.0	0.000	0.000	14.6	3519	29.5	19.8	247.3	4.3	64.7	90.61	1.552	0.2250	0.0	2	0
452.00	58.1	0.0	-0.10	5.83	3	0	0.0	0.0	0.000	0.000	14.6	3512	25.1	16.8	207.8	4.3	65.6	89.83	1.556	0.2255	0.0	2	0
453.00	58.0	0.0	-0.10	5.84	3	0	0.0	0.0	0.000	0.000	14.6	3506	25.0	16.7	206.8	4.3	65.7	89.82	1.560	0.2260	0.0	2	0
454.00	58.0	0.0	0.00	5.86	3	0	0.0	0.0	0.000	0.000	14.6	3506	29.4	19.6	245.3	4.3	64.8	90.61	1.565	0.2267	0.0	2	0
455.00	58.0	0.0	0.00	5.88	3	0	0.0	0.0	0.000	0.000	14.6	3506	29.4	19.6	245.3	4.3	64.7	90.61	1.569	0.2273	0.0	2	0
456.00	58.0	0.0	0.00	5.89	3	0	0.0	0.0	0.000	0.000	14.6	3506	29.4	19.6	245.3	4.3	64.7	90.61	1.574	0.2279	0.0	2	0
457.00	58.0	0.0	0.00	5.91	3	0	0.0	0.0	0.000	0.000	14.6	3506	29.4	19.6	245.3	4.3	64.7	90.61	1.578	0.2286	0.0	2	0
458.00	58.0	0.0	0.00	5.92	3	0	0.0	0.0	0.000	0.100	14.6	3506	29.4	19.6	245.4	4.3	64.7	90.61	1.583	0.2292	0.0	2	0
459.00	57.9	0.0	-0.10	5.94	3	0	0.0	0.0	0.000	0.000	14.6	3501	24.9	16.6	206.1	4.3	65.7	89.81	1.586	0.2297	0.0	2	0
460.00	57.9	0.0	0.00	5.96	3	0	0.0	0.0	0.000	0.000	14.6	3501	29.3	19.6	244.5	4.3	64.7	90.61	1.591	0.2304	0.0	2	0
461.00	58.0	0.0	0.10	5.97	3	0	0.0	0.0	0.000	0.000	14.6	3506	33.8	22.6	285.6	4.3	63.8	91.09	1.596	0.2312	0.0	2	0
462.00	58.1	0.0	0.10	5.99	3	0	0.0	0.0	0.000	0.000	14.6	3512	33.9	22.7	286.8	4.3	63.7	91.08	1.601	0.2320	0.0	2	0
463.00	58.1	0.0	0.00	6.00	3	0	0.0	0.0	0.000	0.000	14.6	3512	29.5	19.7	246.5	4.3	64.7	90.61	1.606	0.2326	0.0	2	0
464.00	58.2	0.0	0.10	6.02	3	0	0.0	0.0	0.000	0.000	14.6	3519	33.9	22.7	288.0	4.3	63.7	91.08	1.611	0.2334	0.0	2	0
465.00	58.3	0.0	0.10	6.04	3	0	0.0	0.0	0.000	0.000	14.6	3525	34.0	22.6	289.3	4.3	63.6	91.07	1.616	0.2342	0.0	2	0
466.00	58.3	0.0	0.00	6.05	3	0	0.0	0.0	0.000	0.000	14.6	3525	29.6	19.9	248.7	4.3	64.6	90.61	1.621	0.2349	0.0	2	0
467.00	58.3	0.0	0.00	6.07	3	0	0.0	0.0	0.000	0.000	14.6	3525	29.6	19.9	248.8	4.3	64.6	90.61	1.625	0.2355	0.0	2	0
468.00	58.2	0.0	-0.10	6.09	3	0	0.0	0.0	0.000	0.000	14.6	3519	25.1	16.8	209.0	4.3	65.5	89.83	1.629	0.2361	0.0	2	0
469.00	58.1	0.0	-0.10	6.10	3	0	0.0	0.0	0.000	0.000	14.6	3512	25.1	16.8	208.0	4.3	65.6	89.82	1.633	0.2366	0.0	2	0
470.00	58.0	0.0	-0.10	6.12	3	0	0.0	0.0	0.000	0.000	14.6	3506	25.0	16.7	207.1	4.3	65.6	89.82	1.637	0.2371	0.0	2	0
471.00	57.8	0.0	-0.20	6.13	3	0	0.0	0.0	0.000	0.000	14.6	3495	20.5	13.6	168.5	4.3	66.5	88.52	1.640	0.2375	0.0	2	0
472.00	57.5	0.0	-0.30	6.15	3	0	0.0	0.0	0.000	0.000	14.6	3476	15.9	10.5	130.7	4.3	67.4	86.35	1.6[illegible]	0.2377	0.0	2	0
473.00	57.1	0.0	-0.40	6.17	3	0	0.0	0.0	0.000	0.000	14.6	3453	11.3	7.4	94.0	4.4	68.3	82.33	1.644	0.2379	0.0	2	0
474.00	57.0	0.0	-0.10	6.18	3	0	0.0	0.0	0.000	0.000	14.6	3448	24.4	16.0	198.1	4.4	65.8	89.75	1.648	0.2384	0.0	2	0
475.00	56.6	0.0	-0.40	6.20	3	0	0.0	0.0	0.000	0.000	14.6	3423	11.0	7.2	90.9	4.4	68.3	82.01	1.650	0.2386	0.0	2	0
476.00	56.1	0.0	-0.50	6.21	3	0	0.0	0.0	0.000	0.000	14.6	3395	6.3	4.1	55.6	4.5	69.2	72.86	1.651	0.2387	0.0	2	0
477.00	56.0	0.0	-0.10	6.23	3	0	0.0	0.0	0.000	0.000	14.6	3388	23.8	15.4	189.3	4.5	66.0	89.67	1.654	0.2391	0.0	2	0
478.00	55.6	0.0	-0.20	6.24	3	0	0.0	0.0	0.000	0.000	14.6	3377	19.3	12.4	152.7	4.5	66.9	88.18	1.657	0.2395	0.0	2	0
479.00	55.5	0.0	-0.30	6.26	3	0	0.0	0.0	0.000	0.000	14.6	3359	14.8	9.4	116.6	4.5	67.7	85.67	1.660	0.2397	0.0	2	0
480.00	55.2	0.0	-0.30	6.27	3	0	0.0	0.0	0.000	0.000	14.6	3341	14.6	9.3	114.8	4.5	67.8	85.35	1.662	0.2399	0.0	2	0
481.00	55.1	0.0	-0.10	6.29	3	0	0.0	0.0	0.000	0.000	14.6	3335	23.3	14.8	181.8	4.6	66.2	89.59	1.665	0.2404	0.0	2	0
482.00	55.0	0.0	-0.10	6.31	3	0	0.0	0.0	0.000	0.000	14.6	3329	23.3	14.7	180.9	4.6	66.2	89.58	1.669	0.2408	0.0	2	0
483.00	54.9	0.0	-0.10	6.32	3	0	0.0	0.0	0.000	0.000	14.6	3324	23.2	14.7	180.2	4.6	66.2	89.56	1.672	0.2412	0.0	2	0
484.00	54.9	0.0	0.00	6.34	3	0	0.0	0.0	0.000	0.000	14.6	3324	27.6	17.5	215.6	4.6	65.3	90.54	1.676	0.2417	0.0	2	0
485.00	54.9	0.0	0.00	6.35	3	0	0.0	0.0	0.000	0.000	14.6	3324	27.6	17.5	215.6	4.6	65.3	90.54	1.680	0.2423	0.0	2	0
486.00	54.9	0.0	0.00	6.37	3	0	0.0	0.0	0.000	0.000	14.6	3324	27.6	17.5	215.7	4.6	65.3	90.54	1.684	0.2428	0.0	2	0
487.00	54.9	0.0	0.00	6.38	3	0	0.0	0.0	0.000	0.000	14.6	3324	27.6	17.5	215.7	4.6	65.3	90.54	1.688	0.2434	0.0	2	0
488.00	54.9	0.0	0.00	6.40	3	0	0.0	0.0	0.000	0.000	14.6	3324	27.6	17.5	215.7	4.6	65.3	90.54	1.692	0.2439	0.0	2	0
489.00	55.0	0.0	0.10	6.41	3	0	0.0	0.0	0.000	0.000	14.6	3329	32.0	20.3	253.5	4.6	64.4	91.15	1.697	0.2446	0.0	2	0
490.00	55.0	0.0	0.00	6.43	3	0	0.0	0.0	0.000	0.000	14.6	3329	27.7	17.5	216.6	4.6	65.3	90.55	1.701	0.2451	0.0	2	0
491.00	55.0	0.0	0.00	6.44	3	0	0.0	0.0	0.000	0.000	14.6	3329	27.7	17.5	[illegible]	4.6	65.3	90.55	1.705	0.2457	0.0	2	0
492.00	55.0	0.0	0.00	6.46	3	0	0.0	0.0	0.000	0.000	14.6	3329	27.7	17.5	216.6	4.6	65.3	90.55	1.709	0.2462	0.0	2	0
493.00	55.0	0.0	0.00	6.47	3	0	0.0	0.0	0.000	0.000	14.6	3329	27.7	17.5	216.6	4.6	65.3	90.55	1.713	0.2467	0.0	2	0
494.00	55.0	0.0	0.00	6.49	3	0	0.0	0.0	0.000	0.000	14.6	3329	27.7	17.5	216.6	4.6	65.3	90.55	1.717	0.2473	0.0	2	0
495.00	55.1	0.0	0.10	6.50	3	0	0.0	0.0	0.000	0.000	14.6	3335	32.1	20.4	254.6	4.6	64.4	91.15	1.721	0.2480	0.0	2	0
496.00	55.1	0.0	0.00	6.52	3	0	0.0	0.0	0.000	0.000	14.6	3335	27.7	17.6	217.6	4.6	65.2	90.55	1.725	0.2485	0.0	2	0
497.00	55.0	0.0	-0.10	6.53	3	0	0.0	0.0	0.000	0.000	14.6	3329	23.3	14.7	181.1	4.6	66.1	89.57	1.729	0.2489	0.0	2	0
498.00	54.9	0.0	-0.10	6.55	3	0	0.0	0.0	0.000	0.000	14.6	3324	23.2	14.7	180.4	4.6	66.1	89.56	1.732	0.2494	0.0	2	0
499.00	54.9	0.0	0.00	6.56	3	0	0.0	0.0	0.000	0.000	14.6	3324	27.6	17.5	215.9	4.6	65.3	90.54	1.736	0.2499	0.0	2	0
500.00	54.8	0.0	-0.10	6.58	3	0	0.0	0.0	0.000	0.000	14.6	3318	23.1	14.6	179.5	4.6	66.1	89.55	1.740	0.2503	0.0	2	0

501.00	54.7	0.0	-0.10	6.60	3	0	0.0	0.0	0.000	0.000	14.6	3312	23.1	14.6	178.7	4.6	66.1	89.54	1.743	0.2507	0.0	2	0
502.00	54.6	0.0	-0.10	6.61	3	0	0.0	0.0	0.000	0.000	14.6	3305	23.0	14.5	177.9	4.6	66.2	89.53	1.746	0.2512	0.0	2	0
503.00	54.4	0.0	-0.20	6.63	3	0	0.0	0.0	0.000	0.000	14.6	3294	19.5	11.6	142.5	4.6	67.6	87.91	1.749	0.2515	0.0	2	0
504.00	54.3	0.0	-0.10	6.64	3	0	0.0	0.0	0.000	0.000	14.6	3288	22.9	14.3	175.5	4.6	66.2	89.50	1.752	0.2519	0.0	2	0
505.00	54.3	0.0	0.00	6.66	3	0	0.0	0.0	0.000	0.000	14.6	3288	27.3	17.1	210.4	4.6	65.4	90.51	1.756	0.2524	0.0	2	0
506.00	54.2	0.0	-0.10	6.67	3	0	0.0	0.0	0.000	0.000	14.6	3282	22.8	14.3	174.7	4.6	66.2	89.49	1.760	0.2528	0.0	2	0
507.00	54.1	0.0	-0.10	6.69	3	0	0.0	0.0	0.000	0.000	14.6	3277	22.8	14.2	174.6	4.7	66.2	89.47	1.763	0.2532	0.0	2	0
508.00	54.1	0.0	0.00	6.70	3	0	0.0	0.0	0.000	0.000	14.6	3276	27.1	16.9	206.6	4.7	65.4	90.51	1.767	0.2537	0.0	2	0
509.00	54.1	0.0	0.00	6.72	3	0	0.0	0.0	0.000	0.000	14.6	3276	27.1	16.9	206.6	4.7	65.4	90.50	1.771	0.2542	0.0	2	0
510.00	54.0	0.0	-0.10	6.73	3	0	0.0	0.0	0.000	0.000	14.6	3271	22.7	14.1	173.4	4.7	66.3	89.46	1.774	0.2546	0.0	2	0
511.00	54.0	0.0	0.00	6.75	3	0	0.0	0.0	0.000	0.000	14.6	3271	27.1	16.9	207.8	4.7	65.4	90.50	1.778	0.2551	0.0	2	0
512.00	54.0	0.0	0.00	6.76	3	0	0.0	0.0	0.000	0.000	14.6	3271	27.1	16.9	207.9	4.7	65.4	90.50	1.782	0.2557	0.0	2	0
513.00	54.0	0.0	0.00	6.78	3	0	0.0	0.0	0.000	0.000	14.6	3271	27.1	16.9	207.9	4.7	65.4	90.50	1.786	0.2562	0.0	2	0
514.00	54.0	0.0	0.00	6.79	3	0	0.0	0.0	0.000	0.000	14.6	3271	27.1	16.9	207.9	4.7	65.4	90.50	1.789	0.2567	0.0	2	0
515.00	54.0	0.0	0.00	6.81	3	0	0.0	0.0	0.000	0.000	14.6	3271	27.1	16.9	207.9	4.7	65.4	90.50	1.793	0.2572	0.0	2	0
516.00	54.0	0.0	0.00	6.82	3	0	0.0	0.0	0.000	0.000	14.6	3271	27.1	16.9	207.9	4.7	65.4	90.50	1.797	0.2577	0.0	2	0
517.00	54.0	0.0	0.00	6.84	3	0	0.0	0.0	0.000	0.000	14.6	3271	27.1	16.9	207.9	4.7	65.4	90.50	1.801	0.2582	0.0	2	0
518.00	54.1	0.0	0.10	6.85	3	0	0.0	0.0	0.000	0.000	14.6	3276	31.5	19.7	244.8	4.7	64.5	91.15	1.805	0.2589	0.0	2	0
519.00	54.2	0.0	0.10	6.87	3	0	0.0	0.0	0.000	0.000	14.6	3282	31.6	19.7	245.9	4.6	64.5	91.15	1.810	0.2595	0.0	2	0
520.00	54.5	0.0	0.30	6.88	3	0	0.0	0.0	0.000	0.000	14.6	3299	40.6	25.5	326.7	4.6	62.5	91.71	1.816	0.2605	0.0	2	0
521.00	54.8	0.0	0.30	6.90	3	0	0.0	0.0	0.000	0.000	14.6	3318	40.7	25.7	330.6	4.6	62.4	91.68	1.822	0.2615	0.0	2	0
522.00	54.9	0.0	0.10	6.91	3	0	0.0	0.0	0.000	0.000	14.6	3324	32.0	20.2	253.2	4.6	64.3	91.15	1.826	0.2621	0.0	2	0
523.00	55.0	0.0	0.10	6.93	3	0	0.0	0.0	0.000	0.000	14.6	3329	32.0	20.3	254.1	4.6	64.3	91.15	1.831	0.2628	0.0	2	0
524.00	55.1	0.0	0.10	6.94	3	0	0.0	0.0	0.000	0.000	14.6	3335	32.1	20.4	255.2	4.6	64.2	91.15	1.835	0.2635	0.0	2	0
525.00	55.2	0.0	0.10	6.96	3	0	0.0	0.0	0.000	0.000	14.6	3341	32.2	20.5	256.3	4.5	64.2	91.14	1.840	0.2642	0.0	2	0
526.00	55.2	0.0	0.00	6.97	3	0	0.0	0.0	0.000	0.000	14.6	3341	27.8	17.7	219.0	4.5	65.1	90.55	1.844	0.2647	0.0	2	0
527.00	55.3	0.0	0.10	6.99	3	0	0.0	0.0	0.000	0.000	14.6	3348	32.2	20.5	257.4	4.5	64.2	91.14	1.849	0.2654	0.0	2	0
528.00	55.4	0.0	0.10	7.00	3	0	0.0	0.0	0.000	0.000	14.6	3352	32.3	20.6	258.4	4.5	64.1	91.14	1.853	0.2661	0.0	2	0
529.00	55.5	0.0	0.10	7.02	3	0	0.0	0.0	0.000	0.000	14.6	3359	32.3	20.7	259.5	4.5	64.1	91.14	1.858	0.2668	0.0	2	0
530.00	55.6	0.0	0.10	7.03	3	0	0.0	0.0	0.000	0.000	14.6	3365	32.4	20.8	260.6	4.5	64.1	91.14	1.863	0.2675	0.0	2	0
531.00	55.7	0.0	0.10	7.05	3	0	0.0	0.0	0.000	0.000	14.6	3371	32.5	20.8	261.7	4.5	64.0	91.13	1.868	0.2682	0.0	2	0
532.00	55.8	0.0	0.10	7.07	3	0	0.0	0.0	0.000	0.000	14.6	3377	32.5	20.9	262.8	4.5	64.0	91.13	1.872	0.2689	0.0	2	0
533.00	55.9	0.0	0.10	7.08	3	0	0.0	0.0	0.000	0.000	14.6	3382	32.6	21.0	263.8	4.5	64.0	91.13	1.877	0.2696	0.0	2	0
534.00	56.0	0.0	0.10	7.10	3	0	0.0	0.0	0.000	0.000	14.6	3388	32.6	21.1	265.0	4.5	63.9	91.13	1.882	0.2704	0.0	2	0
535.00	56.0	0.0	0.00	7.11	3	0	0.0	0.0	0.000	0.000	14.6	3388	28.2	18.2	226.8	4.5	64.8	90.57	1.886	0.2709	0.0	2	0
536.00	56.0	0.0	0.00	7.13	3	0	0.0	0.0	0.000	0.000	14.6	3389	28.2	18.2	226.8	4.5	64.8	90.57	1.890	0.2715	0.0	2	0
537.00	56.0	0.0	0.00	7.14	3	0	0.0	0.0	0.000	0.000	14.6	3388	28.2	18.2	226.8	4.5	64.8	90.57	1.894	0.2721	0.0	2	0
538.00	56.0	0.0	0.00	7.16	3	0	0.0	0.0	0.000	0.000	14.6	3388	28.2	18.2	226.8	4.5	64.8	90.57	1.899	0.2727	0.0	2	0
539.00	56.0	0.0	0.00	7.17	3	0	0.0	0.0	0.000	0.000	14.6	3388	28.2	18.2	226.9	4.5	64.8	90.57	1.903	0.2733	0.0	2	0
540.00	56.0	0.0	0.00	7.19	3	0	0.0	0.0	0.000	0.000	14.6	3388	28.2	18.2	226.9	4.5	64.8	90.57	1.907	0.2738	0.0	2	0
541.00	56.0	0.0	0.00	7.21	3	0	0.0	0.0	0.000	0.000	14.6	3388	28.2	18.2	226.9	4.5	64.8	90.57	1.911	0.2744	0.0	2	0
542.00	56.0	0.0	0.00	7.22	3	0	0.0	0.0	0.000	0.000	14.6	3388	28.2	18.2	226.9	4.5	64.8	90.57	1.915	0.2750	0.0	2	0
543.00	56.0	0.0	0.00	7.24	3	0	0.0	0.0	0.000	0.000	14.6	3388	28.2	18.2	226.9	4.5	64.8	90.57	1.919	0.2756	0.0	2	0
544.00	56.0	0.0	0.00	7.25	3	0	0.0	0.0	0.000	0.000	14.6	3388	28.2	18.2	226.9	4.5	64.8	90.57	1.924	0.2761	0.0	2	0
545.00	56.0	0.0	0.00	7.27	3	0	0.0	0.0	0.000	0.000	14.6	3389	28.2	18.2	227.0	4.5	64.8	90.57	1.928	0.2767	0.0	2	0
546.00	56.0	0.0	0.00	7.28	3	0	0.0	0.0	0.000	0.000	14.6	3388	28.2	18.2	227.0	4.5	64.8	90.57	1.932	0.2773	0.0	2	0
547.00	56.0	0.0	0.00	7.30	3	0	0.0	0.0	0.000	0.000	14.6	3388	28.2	18.2	227.0	4.5	64.8	90.57	1.936	0.2779	0.0	2	0
548.00	55.9	0.0	-0.10	7.31	3	0	0.0	0.0	0.000	0.000	14.6	3382	23.8	15.3	189.4	4.5	65.7	89.66	1.940	0.2783	0.0	2	0
549.00	55.9	0.0	0.00	7.33	3	0	0.0	0.0	0.000	0.000	14.6	3382	28.2	18.1	226.0	4.5	64.8	90.57	1.944	0.2789	0.0	2	0
550.00	55.9	0.0	0.00	7.34	3	0	0.0	0.0	0.000	0.000	14.6	3382	28.2	18.1	226.1	4.5	64.8	90.57	1.948	0.2795	0.0	2	0
551.00	55.8	0.0	-0.10	7.36	3	0	0.0	0.0	0.000	0.000	14.6	3377	23.7	15.3	188.6	4.5	65.7	89.65	1.951	0.2799	0.0	2	0
552.00	55.6	0.0	-0.20	7.38	3	0	0.0	0.0	0.000	0.000	14.6	3365	19.2	12.3	151.8	4.5	66.6	88.15	1.954	0.2803	0.0	2	0
553.00	55.4	0.0	-0.20	7.39	3	0	0.0	0.0	0.000	0.000	14.6	3354	19.1	12.2	150.4	4.5	66.6	88.11	1.957	0.2806	0.0	2	0
554.00	55.2	0.0	-0.20	7.41	3	0	0.0	0.0	0.000	0.000	14.6	3341	19.0	12.1	148.8	4.5	66.7	88.07	1.960	0.2809	0.0	2	0
555.00	55.1	0.0	-0.10	7.42	3	0	0.0	0.0	0.000	0.000	14.6	3335	23.3	14.8	182.7	4.6	65.8	89.56	1.963	0.2814	0.0	2	0
556.00	55.0	0.0	-0.10	7.44	3	0	0.0	0.0	0.000	0.000	14.6	3329	23.3	14.7	181.8	4.6	65.8	89.57	1.967	0.2818	0.0	2	0
557.00	54.9	0.0	-0.10	7.45	3	0	0.0	0.0	0.000	0.000	14.6	3324	23.2	14.7	181.1	4.6	65.9	89.56	1.970	0.2822	0.0	2	0
558.00	54.6	0.0	-0.30	7.47	3	0	0.0	0.0	0.000	0.000	14.6	3305	14.2	9.0	111.4	4.6	67.5	85.33	1.972	0.2824	0.0	2	0
559.00	54.4	0.0	-0.20	7.48	3	0	0.0	0.0	0.000	0.000	14.6	3294	18.5	11.6	143.0	4.6	66.8	87.91	1.975	0.2827	0.0	2	0
560.00	54.2	0.0	-0.20	7.50	3	0	0.0	0.0	0.000	0.000	14.6	3282	18.4	11.5	141.5	4.6	66.8	87.86	1.978	0.2830	0.0	2	0
561.00	54.1	0.0	-0.10	7.51	3	0	0.0	0.0	0.000	0.000	14.6	3277	22.8	14.2	174.6	4.7	66.0	89.47	1.981	0.2835	0.0	2	0
562.00	53.8	0.0	-0.30	7.53	3	0	0.0	0.0	0.000	0.000	14.6	3256	13.8	8.6	106.3	4.7	67.7	85.01	1.983	0.2837	0.0	2	0
563.00	53.4	0.0	-0.40	7.54	3	0	0.0	0.0	0.000	0.000	14.6	3235	9.2	5.7	72.7	4.7	68.5	79.56	1.985	0.2838	0.0	2	0

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564.00	53.3	0.0	-0.10	7.56	3	0	0.0	0.0	0.000	0.000	14.6	3243	22.3	15.7	169.2	4.7	66.2	85.58	1.988	0.2842	0.0	2	0
565.00	53.1	0.0	-0.20	7.57	3	0	0.0	0.0	0.000	0.000	14.6	3217	17.8	10.9	155.9	4.6	67.0	87.61	1.990	0.2845	0.0	2	0
566.00	52.9	0.0	-0.20	7.59	3	0	0.0	0.0	0.000	0.000	14.6	3205	17.7	10.8	132.5	4.6	67.0	87.56	1.993	0.2847	0.0	2	0
567.00	52.6	0.0	-0.30	7.60	3	0	0.0	0.0	0.000	0.000	14.6	3188	13.1	8.0	99.0	4.8	67.8	84.47	1.995	0.2849	0.0	2	0
568.00	52.4	0.0	-0.20	7.62	3	0	0.0	0.0	0.000	0.000	14.6	3176	17.4	10.5	129.2	4.8	67.1	87.43	1.997	0.2852	0.0	2	0
569.00	52.2	0.0	-0.20	7.63	3	0	0.0	0.0	0.000	0.000	14.6	3164	17.3	10.4	127.8	4.9	67.1	87.38	2.000	0.2855	0.0	2	0
570.00	52.1	0.0	-0.10	7.65	3	0	0.0	0.0	0.000	0.000	14.6	3158	21.7	13.0	159.2	4.9	66.4	89.21	2.003	0.2858	0.0	2	0
571.00	52.0	0.0	-0.10	7.66	3	0	0.0	0.0	0.000	0.000	14.6	3152	21.6	13.0	158.4	4.9	66.4	89.19	2.006	0.2862	0.0	2	0
572.00	52.0	0.0	0.00	7.67	3	0	0.0	0.0	0.000	0.000	14.6	3152	26.0	15.6	191.4	4.9	65.6	90.37	2.010	0.2866	0.0	2	0
573.00	52.0	0.0	0.00	7.69	3	0	0.0	0.0	0.000	0.000	14.6	3152	26.0	15.6	191.4	4.9	65.6	90.37	2.013	0.2871	0.0	2	0
574.00	52.0	0.0	0.00	7.70	3	0	0.0	0.0	0.000	0.000	14.6	3152	26.0	15.6	191.4	4.9	65.6	90.37	2.017	0.2876	0.0	2	0
575.00	52.1	0.0	0.10	7.72	3	0	0.0	0.0	0.000	0.000	14.6	3158	30.4	18.3	226.6	4.9	64.7	91.12	2.021	0.2881	0.0	2	0
576.00	52.0	0.0	-0.10	7.73	3	0	0.0	0.0	0.000	0.000	14.6	3152	21.6	13.0	158.5	4.9	66.4	89.19	2.024	0.2885	0.0	2	0
577.00	52.0	0.0	0.00	7.75	3	0	0.0	0.0	0.000	0.000	14.6	3152	26.0	15.6	191.5	4.9	65.6	90.36	2.027	0.2890	0.0	2	0
578.00	51.9	0.0	-0.10	7.76	3	0	0.0	0.0	0.000	0.000	14.6	3147	21.5	12.9	157.8	4.9	66.4	89.18	2.030	0.2893	0.0	2	0
579.00	51.6	0.0	-0.30	7.78	3	0	0.0	0.0	0.000	0.000	14.6	3129	12.6	7.5	93.3	4.9	67.9	83.98	2.032	0.2895	0.0	2	0
580.00	51.4	0.0	-0.20	7.79	3	0	0.0	0.0	0.000	0.000	14.6	3117	16.9	10.0	122.7	5.0	67.2	87.16	2.035	0.2897	0.0	2	0
581.00	51.1	0.0	-0.30	7.80	3	0	0.0	0.0	0.000	0.000	14.6	3100	12.3	7.3	90.5	5.0	68.0	83.72	2.036	0.2899	0.0	2	0
582.00	50.7	0.0	-0.40	7.82	3	0	0.0	0.0	0.000	0.000	14.6	3076	7.8	4.5	59.1	5.0	68.7	76.77	2.038	0.2900	0.0	2	0
583.00	50.3	0.0	-0.40	7.83	3	0	0.0	0.0	0.000	0.000	14.6	3052	7.5	4.4	57.2	5.1	68.8	76.29	2.039	0.2901	0.0	2	0
584.00	49.8	0.0	-0.50	7.85	3	0	0.0	0.0	0.000	0.000	14.6	3023	2.9	1.7	27.1	5.2	69.5	55.57	2.040	0.2902	0.0	2	0
585.00	49.3	0.0	-0.50	7.86	3	0	0.0	0.0	0.000	0.000	14.6	2993	2.6	1.5	25.2	5.2	69.6	53.28	2.040	0.2902	0.0	2	0
586.00	48.7	0.0	-0.60	7.87	3	0	0.0	0.0	0.000	0.000	0.0	2958	-2.0	-1.1	-3.5	5.3	70.3	53.28	2.040	0.2902	0.0	2100	
587.00	48.2	0.0	-0.50	7.89	3	0	0.0	0.0	0.000	0.000	0.0	2928	2.1	1.2	21.1	5.4	69.7	47.40	2.041	0.2902	0.0	2	0
588.00	48.1	0.0	-0.10	7.90	3	0	0.0	0.0	0.000	0.000	0.0	2921	19.6	10.9	131.8	5.4	67.0	88.45	2.043	0.2905	0.0	2	0
589.00	48.0	0.0	-0.10	7.91	3	0	0.0	0.0	0.000	0.000	0.0	2915	19.5	10.8	131.1	5.4	67.0	88.42	2.046	0.2908	0.0	2	0
590.00	48.0	0.0	0.00	7.93	3	0	0.0	0.0	0.000	0.000	0.0	2915	23.9	13.3	160.8	5.4	66.3	89.92	2.049	0.2912	0.0	2	0
591.00	48.1	0.0	0.10	7.94	3	0	0.0	0.0	0.000	0.000	0.0	2920	28.4	15.8	192.0	5.4	65.5	90.91	2.052	0.2916	0.0	2	0
592.00	48.4	0.0	0.30	7.95	3	0	0.0	0.0	0.000	0.000	0.0	2937	37.3	20.8	259.4	5.4	63.9	91.94	2.057	0.2923	0.0	2	0
593.00	48.9	0.0	0.50	7.97	3	0	0.0	0.0	0.000	0.000	0.0	2966	46.3	26.1	335.2	5.3	62.0	92.21	2.063	0.2933	0.0	2	0
594.00	49.0	0.0	0.10	7.98	3	0	0.0	0.0	0.000	0.000	0.0	2973	28.8	16.3	199.4	5.3	65.3	90.97	2.067	0.2938	0.0	2	0
595.00	49.1	0.0	0.10	7.99	3	0	0.0	0.0	0.000	0.000	0.0	2979	28.9	16.4	200.3	5.3	65.3	90.98	2.070	0.2943	0.0	2	0
596.00	49.1	0.0	0.60	8.01	3	0	0.0	0.0	0.000	0.000	0.0	2979	24.5	13.9	168.8	5.3	66.1	90.07	2.074	0.2947	0.0	2	0
597.00	49.0	0.0	-0.10	8.02	3	0	0.0	0.0	0.000	0.000	0.0	2974	20.0	11.4	137.7	5.3	66.8	88.65	2.076	0.2950	0.0	2	0
598.00	49.0	0.0	0.00	8.04	3	0	0.0	0.0	0.000	0.000	0.0	2974	24.4	13.8	168.1	5.3	66.1	90.06	2.079	0.2954	0.0	2	0
599.00	48.9	0.0	-0.10	8.05	3	0	0.0	0.0	0.000	0.000	0.0	2968	20.0	11.3	137.0	5.3	66.8	88.63	2.082	0.2957	0.0	2	0
600.00	48.6	0.0	-0.30	8.06	3	0	0.0	0.0	0.000	0.000	0.0	2951	11.1	6.2	77.3	5.3	68.3	82.21	2.084	0.2956	0.0	2	0
601.00	48.3	0.0	-0.30	8.08	3	0	0.0	0.0	0.000	0.000	0.0	2933	10.9	6.1	75.9	5.4	68.3	82.01	2.085	0.2959	0.0	2	0
602.00	48.0	0.0	-0.30	8.09	3	0	0.0	0.0	0.000	0.000	0.0	2916	10.8	6.0	74.4	5.4	68.3	81.79	2.087	0.2961	0.0	2	0
603.00	47.9	0.0	-0.10	8.10	3	0	0.0	0.0	0.000	0.000	0.0	2909	19.5	10.8	130.6	5.4	67.0	88.40	2.089	0.2964	0.0	2	0
604.00	47.6	0.0	-0.10	8.12	3	0	0.0	0.0	0.000	0.000	0.0	2902	19.4	10.7	129.9	5.4	67.0	88.38	2.092	0.2966	0.0	2	0
605.00	47.7	0.0	-0.10	8.13	3	0	0.0	0.0	0.000	0.000	0.0	2897	19.4	10.7	129.4	5.4	67.0	88.35	2.094	0.2969	0.0	2	0
606.00	47.9	0.0	0.20	8.14	3	0	0.0	0.0	0.000	0.000	0.0	2907	32.6	18.1	222.0	5.4	64.7	91.53	2.098	0.2975	0.0	2	0
607.00	48.3	0.0	0.40	8.16	3	0	0.0	0.0	0.000	0.000	0.0	2931	41.6	23.2	292.8	5.4	63.0	92.16	2.104	0.2983	0.0	2	0
608.00	49.0	0.0	0.70	8.17	3	0	0.0	0.0	0.000	0.000	0.0	2971	55.1	31.2	415.7	5.3	60.0	92.02	2.111	0.2997	0.0	2	0
609.00	49.1	0.0	0.10	8.18	3	0	0.0	0.0	0.000	0.000	0.0	2979	28.9	16.4	200.4	5.3	65.2	90.98	2.114	0.3002	0.0	2	0
610.00	49.0	0.0	-0.10	8.20	3	0	0.0	0.0	0.000	0.000	0.0	2974	20.0	11.4	137.7	5.3	66.8	88.65	2.117	0.3005	0.0	2	0
611.00	48.9	0.0	-0.10	8.21	3	0	0.0	0.0	0.000	0.000	0.0	2968	20.0	11.3	137.1	5.3	66.8	88.63	2.120	0.3007	0.0	2	0
612.00	48.0	0.0	-0.90	8.22	3	0	0.0	0.0	0.000	0.000	0.0	2917	-15.5	-8.6	-60.5	5.4	72.1	88.63	2.118	0.3006	0.0	2100	
613.00	47.1	0.0	-0.90	8.24	3	0	0.0	0.0	0.000	0.000	0.0	2865	-16.0	-8.7	-61.6	5.5	72.1	88.63	2.117	0.3005	0.0	2100	
614.00	46.2	0.0	-0.90	8.25	3	0	0.0	0.0	0.000	0.000	0.0	2812	-16.4	-8.8	-62.5	5.7	72.1	88.63	2.115	0.3004	0.0	2100	
615.00	46.1	0.0	-0.10	8.26	3	0	0.0	0.0	0.000	0.000	0.0	2802	18.6	9.9	119.7	5.7	67.2	87.93	2.117	0.3006	0.0	2	0
616.00	46.1	0.0	0.00	8.28	3	0	0.0	0.0	0.000	0.000	0.0	2801	23.0	12.3	147.8	5.7	66.5	89.61	2.120	0.3010	0.0	2	0
617.00	46.2	0.0	0.10	8.29	3	0	0.0	0.0	0.000	0.000	0.0	2807	27.4	14.7	177.5	5.7	65.8	90.72	2.124	0.3014	0.0	2	0
618.00	46.9	0.0	0.70	8.30	3	0	0.0	0.0	0.000	0.000	0.0	2845	54.0	29.3	384.0	5.6	60.8	92.27	2.130	0.3026	0.0	2	0
619.00	47.7	0.1	0.83	8.31	3	0	0.0	0.0	0.000	0.000	0.0	2895	66.2	33.2	449.9	5.5	59.1	91.91	2.138	0.3041	0.0	2310	
620.00	49.0	0.0	1.27	8.33	3	2969	87.9	49.7	23.332	0.473	14.5	2969	-7.1	-4.0	8.7	5.3	69.9	*******	2.138	0.3041	0.0	3	0
621.00	49.7	0.0	0.70	8.34	3	0	0.0	0.0	0.000	0.000	14.5	3013	55.9	32.1	431.5	5.2	59.6	91.89	2.145	0.3056	0.0	2	0
622.00	50.4	0.2	0.72	8.36	3	0	0.0	0.0	0.000	0.000	14.5	3056	56.8	33.1	449.8	5.1	59.1	91.74	2.153	0.3071	0.0	2310	
623.00	51.5	0.0	1.08	8.37	3	3119	87.7	52.1	24.742	0.475	14.5	3119	-14.1	-8.4	9.7	5.0	69.8	******	2.153	0.3071	0.0	3	0
624.00	52.2	0.0	0.70	8.38	3	3163	87.6	52.7	25.081	0.476	14.6	3163	-30.3	-18.3	9.9	4.9	69.8	******	2.153	0.3071	0.0	3	0
625.00	52.7	0.0	0.50	8.40	3	0	0.0	0.0	0.000	0.000	14.6	3193	46.6	29.6	391.8	4.8	60.5	91.81	2.160	0.3084	0.0	2	0
626.00	53.0	0.0	0.30	8.41	3	0	0.0	0.0	0.000	0.000	14.6	3211	39.7	24.3	311.0	4.8	62.5	91.77	2.165	0.3093	0.0	2	0

627.00	53.6	0.0	0.00	8.43	3	0	0.0	0.0	0.000	0.000	14.6	3246	53.2	32.9	446.8	4.7	59.1	91.50	2.173	0.3118	0.0	2	0
628.00	54.0	0.0	0.40	8.44	3	0	0.0	0.0	0.000	0.000	14.6	3269	44.7	27.8	364.9	4.7	61.2	91.74	2.179	0.3119	0.0	2	0
629.00	54.1	0.0	0.10	8.46	3	0	0.0	0.0	0.000	0.000	14.6	3276	31.5	19.7	246.7	4.7	64.6	91.13	2.185	0.3126	0.0	2	0
630.00	54.4	0.0	0.30	8.47	3	0	0.0	0.0	0.000	0.000	14.6	3294	40.5	25.4	320.5	4.6	62.0	91.67	2.189	0.3136	0.0	2	0
631.00	54.7	0.0	0.30	8.49	3	0	0.0	0.0	0.000	0.000	14.6	3312	41.7	25.6	332.4	4.6	61.9	91.64	2.195	0.3145	0.0	2	0
632.00	55.1	0.0	0.40	8.50	3	0	0.0	0.0	0.000	0.000	14.6	3335	45.3	28.8	361.0	4.6	61.7	91.61	2.202	0.3157	0.0	2	0
633.00	55.4	0.0	0.30	8.52	3	0	0.0	0.0	0.000	0.000	14.6	3352	41.1	26.2	341.6	4.5	61.7	91.58	2.207	0.3168	0.0	2	0
634.00	55.4	0.0	0.00	8.53	3	0	0.0	0.0	0.000	0.000	14.6	3354	27.9	17.8	222.5	4.5	64.6	90.54	2.212	0.3173	0.0	2	0
635.00	55.0	0.0	-0.40	8.55	3	0	0.0	0.0	0.000	0.000	14.6	3329	10.1	6.4	82.0	4.6	68.0	80.90	2.213	0.3175	0.0	2	0
636.00	54.5	0.0	-0.50	8.56	3	0	0.0	0.0	0.000	0.000	14.6	3300	5.4	3.4	47.9	4.6	68.9	69.50	2.214	0.3176	0.0	2	0
637.00	53.6	0.0	-0.90	8.58	3	0	0.0	0.0	0.000	0.000	0.0	3247	-12.7	-7.8	-70.8	4.7	71.6	69.90	2.215	0.3175	0.0	2	100
638.00	52.5	0.0	-1.10	8.59	3	0	0.0	0.0	0.000	0.000	0.0	3183	-22.0	-13.4	-125.3	4.8	73.1	69.90	2.210	0.3173	0.0	2	100
639.00	50.2	0.0	-2.30	8.61	3	0	0.0	0.0	0.000	0.000	0.0	3050	-75.9	-44.1	-392.5	5.1	79.6	69.90	2.202	0.3167	0.0	2	100
640.00	48.2	0.0	-2.00	8.62	3	0	0.0	0.0	0.000	0.000	0.0	2933	-63.7	-35.6	-324.1	5.4	78.0	69.90	2.195	0.3162	0.0	2	100
641.00	46.5	0.0	-1.70	8.64	3	0	0.0	0.0	0.000	0.000	0.0	2833	-51.3	-27.7	-257.6	5.6	76.3	69.50	2.190	0.3159	0.0	2	100
642.00	46.2	0.0	-0.30	8.65	3	0	0.0	0.0	0.000	0.000	0.0	2808	9.9	5.3	66.2	5.7	68.4	80.41	2.191	0.3160	0.0	2	0
643.00	46.0	0.0	-0.20	8.66	3	0	0.0	0.0	0.000	0.000	0.0	2796	14.2	7.6	91.9	5.7	67.8	85.15	2.193	0.3162	0.0	2	0
644.00	46.0	0.0	0.00	8.67	3	0	0.0	0.0	0.000	0.000	0.0	2796	22.9	12.2	147.4	5.7	66.4	89.59	2.196	0.3165	0.0	2	0
645.00	46.3	0.0	0.30	8.69	3	0	0.0	0.0	0.000	0.000	0.0	2812	36.2	19.4	239.8	5.7	64.1	91.91	2.200	0.3171	0.0	2	0
646.00	46.8	0.0	0.50	8.70	3	0	0.0	0.0	0.000	0.000	0.0	2840	45.2	24.5	311.2	5.6	62.4	92.32	2.205	0.3180	0.0	2	0
647.00	47.5	0.0	0.70	8.71	3	0	0.0	0.0	0.000	0.000	0.0	2881	54.3	29.8	394.2	5.5	60.3	92.18	2.212	0.3193	0.0	2	0
648.00	48.2	0.0	0.70	8.73	3	0	0.0	0.0	0.000	0.000	0.0	2923	54.7	30.5	405.1	5.4	60.1	92.09	2.219	0.3206	0.0	2	0
649.00	48.8	0.0	0.60	8.74	3	0	0.0	0.0	0.000	0.000	0.0	2959	50.6	28.5	374.3	5.3	60.8	92.15	2.225	0.3218	0.0	2	0
650.00	49.5	0.0	0.70	8.75	3	0	0.0	0.0	0.000	0.000	0.0	3002	55.4	31.6	426.1	5.2	59.5	91.91	2.233	0.3232	0.0	2	0
651.00	50.2	0.0	0.70	8.77	3	0	0.0	0.0	0.000	0.000	0.0	3042	55.7	32.3	437.7	5.1	59.2	91.86	2.240	0.3246	0.0	2	0
652.00	50.7	0.0	0.50	8.78	3	0	0.0	0.0	0.000	0.000	0.0	3073	47.2	27.6	361.6	5.0	61.1	92.02	2.246	0.3258	0.0	2	0
653.00	51.1	0.0	0.40	8.80	3	0	0.0	0.0	0.000	0.000	0.0	3097	43.1	25.4	327.5	5.0	61.9	91.99	2.252	0.3267	0.0	2	0
654.00	51.7	0.0	0.60	8.81	3	0	0.0	0.0	0.000	0.000	0.0	3133	52.2	31.1	418.8	4.9	59.7	91.76	2.259	0.3281	0.0	2	0
655.00	52.2	0.0	0.50	8.82	3	0	0.0	0.0	0.000	0.000	0.0	3163	48.0	28.9	383.2	4.9	60.5	91.85	2.265	0.3293	0.0	2	0
656.00	52.5	0.0	0.30	8.84	3	0	0.0	0.0	0.000	0.000	0.0	3181	39.4	23.9	306.1	4.8	62.4	91.79	2.271	0.3302	0.0	2	0
657.00	52.1	0.0	-0.40	8.85	3	0	0.0	0.0	0.000	0.000	0.0	3159	6.5	5.1	66.2	4.9	68.3	78.34	2.272	0.3303	0.0	2	0
658.00	51.6	0.0	-0.50	8.87	3	0	0.0	0.0	0.000	0.000	0.0	3129	3.8	2.3	34.6	4.9	69.1	62.37	2.273	0.3304	0.0	2	0
659.00	51.1	0.0	-0.50	8.88	3	0	0.0	0.0	0.000	0.000	0.0	3100	3.6	2.1	32.4	5.0	69.1	60.69	2.274	0.3304	0.0	2	0
660.00	51.0	0.0	-0.10	8.90	3	0	0.0	0.0	0.000	0.000	0.0	3093	21.1	12.4	152.0	5.0	66.2	89.03	2.276	0.3308	0.0	2	0
661.00	51.0	0.0	0.00	8.91	3	0	0.0	0.0	0.000	0.000	0.0	3092	25.5	15.0	164.3	5.0	65.4	90.28	2.280	0.3312	0.0	2	0
662.00	51.1	0.0	0.10	8.92	3	0	0.0	0.0	0.000	0.000	0.0	3098	29.9	17.6	218.8	5.0	64.6	91.67	2.284	0.3317	0.0	2	0
663.00	51.4	0.0	0.30	8.94	3	0	0.0	0.0	0.000	0.000	0.0	3116	38.8	23.0	295.4	5.0	62.7	91.84	2.289	0.3326	0.0	2	0
664.00	51.7	0.0	0.30	8.95	3	0	0.0	0.0	0.000	0.000	0.0	3133	39.0	23.3	296.8	4.9	62.6	91.83	2.294	0.3334	0.0	2	0
665.00	52.0	0.0	0.30	8.97	3	0	0.0	0.0	0.000	0.000	0.0	3152	39.2	23.5	300.4	4.9	62.5	91.61	2.300	0.3343	0.0	2	0
666.00	52.2	0.0	0.20	8.98	3	0	0.0	0.0	0.000	0.000	0.0	3163	34.9	21.0	265.0	4.9	63.4	91.55	2.304	0.3350	0.0	2	0
667.00	52.5	0.0	0.30	9.00	3	0	0.0	0.0	0.000	0.000	0.0	3181	39.4	23.9	306.4	4.8	62.4	91.78	2.310	0.3359	0.0	2	0
668.00	52.8	0.0	0.30	9.01	3	0	0.0	0.0	0.000	0.000	0.0	3199	39.6	24.1	310.0	4.8	62.3	91.76	2.315	0.3366	0.0	2	0
669.00	52.7	0.0	-0.10	9.03	3	0	0.0	0.0	0.000	0.000	0.0	3194	22.0	13.4	164.7	4.8	65.8	89.29	2.318	0.3371	0.0	2	0
670.00	52.6	0.0	-0.10	9.04	3	0	0.0	0.0	0.000	0.000	0.0	3188	21.9	13.3	164.0	4.8	65.9	89.28	2.321	0.3375	0.0	2	0
671.00	52.3	0.0	-0.30	9.05	3	0	0.0	0.0	0.000	0.000	0.0	3170	13.0	7.8	97.8	4.9	67.5	84.34	2.323	0.3377	0.0	2	0
672.00	52.3	0.0	0.00	9.07	3	0	0.0	0.0	0.000	0.000	0.0	3170	26.2	15.8	195.3	4.9	65.1	90.38	2.327	0.3382	0.0	2	0
673.00	52.4	0.0	0.10	9.08	3	0	0.0	0.0	0.000	0.000	0.0	3175	30.6	18.5	231.0	4.8	64.2	91.11	2.331	0.3388	0.0	2	0
674.00	52.5	0.0	0.10	9.10	3	0	0.0	0.0	0.000	0.000	0.0	3181	30.7	18.6	232.0	4.8	64.2	91.11	2.335	0.3394	0.0	2	0
675.00	52.7	0.0	0.20	9.11	3	0	0.0	0.0	0.000	0.000	0.0	3193	35.2	21.4	270.6	4.8	63.2	91.54	2.340	0.3401	0.0	2	0
676.00	52.7	0.0	0.00	9.13	3	0	0.0	0.0	0.000	0.000	0.0	3194	26.4	16.0	198.6	4.8	65.0	90.41	2.344	0.3406	1.0	2	0
677.00	52.4	0.0	-0.30	9.14	3	0	0.0	0.0	0.000	0.000	0.0	3176	13.0	7.9	96.5	4.8	67.5	84.39	2.346	0.3408	0.0	2	0
678.00	52.1	0.0	-0.30	9.16	3	0	0.0	0.0	0.000	0.000	0.0	3158	12.9	7.7	96.7	4.9	67.5	84.25	2.348	0.3410	0.0	2	0
679.00	51.7	0.0	-0.40	9.17	3	0	0.0	0.0	0.000	0.000	0.0	3134	8.3	4.9	64.3	4.9	68.3	77.92	2.349	0.3411	0.0	2	0
680.00	51.1	0.0	-0.60	9.19	3	0	0.0	0.0	0.000	0.000	0.0	3100	-0.8	-0.5	4.4	5.0	69.8	77.92	2.349	0.3411	0.0	2	100
681.00	50.5	0.0	-0.60	9.20	3	0	0.0	0.0	0.000	0.000	0.0	3065	-1.1	-0.7	2.3	5.1	69.8	77.92	2.349	0.3411	0.0	2	100
682.00	50.1	0.0	-0.40	9.21	3	0	0.0	0.0	0.000	0.000	0.0	3040	7.4	4.3	56.6	5.1	68.5	76.07	2.351	0.3412	0.0	2	0
683.00	49.6	0.0	-0.30	9.23	3	0	0.0	0.0	0.000	0.000	0.0	3023	11.7	6.7	83.9	5.2	67.8	82.99	2.352	0.3414	0.0	2	0
684.00	49.7	0.0	-0.10	9.24	3	0	0.0	0.0	0.000	0.000	0.0	3015	20.4	11.7	143.1	5.2	66.3	88.80	2.355	0.3417	0.0	2	0
685.00	49.6	0.0	-0.10	9.25	3	0	0.0	0.0	0.000	0.000	0.0	3010	20.3	11.7	142.5	5.2	66.4	88.76	2.358	0.3420	0.0	2	0
686.00	49.5	0.0	-0.10	9.27	3	0	0.0	0.0	0.000	0.000	0.0	3004	20.3	11.6	141.6	5.2	66.4	88.76	2.360	0.3425	0.0	2	0
687.00	49.5	0.0	0.00	9.28	3	0	0.0	0.0	0.000	0.000	0.0	3004	24.7	14.1	172.9	5.2	65.6	90.12	2.364	0.3427	0.0	2	0
688.00	49.7	0.0	0.20	9.30	3	0	0.0	0.0	0.000	0.000	0.0	3015	33.6	19.3	240.3	5.2	63.9	91.56	2.368	0.3433	0.0	2	0
689.00	50.0	0.0	0.30	9.31	3	0	0.0	0.0	0.000	0.000	0.0	3033	38.1	22.0	278.3	5.1	63.0	91.89	2.373	0.3441	0.0	2	0

690.00	50.2	0.0	0.20	9.32	3	0	0.0	0.0	0.000	0.000	0.0	3045	35.8	19.6	245.2	5.1	63.5	91.56	2.377	0.3447	0.0	2	0
691.00	50.6	0.0	0.40	9.34	3	0	0.0	0.0	0.000	0.000	0.0	3067	42.6	25.0	324.4	5.1	61.9	92.01	2.383	0.3457	0.0	2	0
692.00	51.1	0.0	0.50	9.35	3	0	0.0	0.0	0.000	0.000	0.0	3097	47.4	28.0	368.7	5.0	60.7	91.96	2.389	0.3468	0.0	2	0
693.00	51.6	0.0	0.50	9.37	3	0	0.0	0.0	0.000	0.000	0.0	3127	47.7	28.4	375.9	4.9	60.5	91.90	2.396	0.3480	0.0	2	0
694.00	51.9	0.0	0.30	9.38	3	0	0.0	0.0	0.000	0.000	0.0	3145	39.1	23.4	300.0	4.9	62.4	91.81	2.401	0.3489	0.0	2	0
695.00	52.0	0.0	0.10	9.40	3	0	0.0	0.0	0.000	0.000	0.0	3152	30.4	18.2	227.6	4.9	64.2	91.10	2.405	0.3495	0.0	2	0
696.00	52.1	0.0	0.10	9.41	3	0	0.0	0.0	0.000	0.000	0.0	3158	30.4	18.3	228.6	4.9	64.2	91.10	2.409	0.3500	0.0	2	0
697.00	52.4	0.0	0.30	9.42	3	0	0.0	0.0	0.000	0.000	0.0	3175	39.4	23.8	306.0	4.8	62.2	91.78	2.415	0.3509	0.0	2	0
698.00	52.9	0.0	0.50	9.44	3	0	0.0	0.0	0.000	0.000	0.0	3205	48.4	29.6	395.6	4.8	60.0	91.73	2.421	0.3522	0.0	2	0
699.00	53.3	0.0	0.40	9.45	3	0	0.0	0.0	0.000	0.000	0.0	3228	44.3	27.2	356.2	4.7	60.9	91.76	2.426	0.3533	0.0	2	0
700.00	53.7	0.0	0.40	9.47	3	0	0.0	0.0	0.000	0.000	0.0	3252	44.5	27.6	363.9	4.7	60.8	91.72	2.434	0.3544	0.0	2	0
701.00	54.2	0.0	0.50	9.48	3	0	0.0	0.0	0.000	0.000	0.0	3282	49.2	30.7	416.3	4.6	59.5	91.54	2.441	0.3558	0.0	2	0
702.00	54.5	0.0	0.30	9.50	3	0	0.0	0.0	0.000	0.000	0.0	3299	40.6	25.5	332.3	4.6	61.5	91.62	2.446	0.3568	0.0	2	0
703.00	54.8	0.0	0.30	9.51	3	0	0.0	0.0	0.000	0.000	0.0	3318	40.7	25.7	336.4	4.6	61.4	91.60	2.452	0.3573	0.0	2	0
704.00	55.0	0.0	0.20	9.53	3	0	0.0	0.0	0.000	0.000	0.0	3329	36.4	23.1	297.4	4.6	62.4	91.44	2.458	0.3586	0.0	2	0
705.00	55.5	0.0	0.50	9.54	3	0	0.0	0.0	0.000	0.000	0.0	3359	49.9	31.9	438.2	4.5	58.9	91.32	2.465	0.3601	0.0	2	0
706.00	55.9	0.0	0.40	9.56	3	0	0.0	0.0	0.000	0.000	0.0	3382	45.8	29.5	396.7	4.5	59.9	91.44	2.471	0.3613	0.0	2	0
707.00	56.1	0.0	0.20	9.58	3	0	0.0	0.0	0.000	0.000	0.0	3395	37.1	24.0	310.9	4.5	62.0	91.37	2.477	0.3622	0.0	2	0
708.00	56.3	0.0	0.20	9.59	3	0	0.0	0.0	0.000	0.000	0.0	3406	37.2	24.1	315.4	4.4	62.0	91.35	2.482	0.3632	0.0	2	0
709.00	56.4	0.0	0.10	9.61	3	0	0.0	0.0	0.000	0.000	0.0	3412	32.9	21.3	273.3	4.4	62.9	91.07	2.487	0.3639	0.0	2	0
710.00	56.5	0.0	0.10	9.62	3	0	0.0	0.0	0.000	0.000	0.0	3418	32.9	21.4	274.5	4.4	62.9	91.06	2.492	0.3647	0.0	2	0
711.00	56.7	0.0	0.20	9.64	3	0	0.0	0.0	0.000	0.000	0.0	3431	37.4	24.5	318.7	4.4	61.8	91.32	2.498	0.3656	0.0	2	0
712.00	56.9	0.0	0.20	9.65	3	0	0.0	0.0	0.000	0.000	0.0	3442	37.6	24.6	321.2	4.4	61.7	91.30	2.503	0.3665	0.0	2	0
713.00	57.0	0.0	0.10	9.67	3	0	0.0	0.0	0.000	0.000	0.0	3448	35.2	21.8	280.3	4.4	62.7	91.04	2.508	0.3673	0.0	2	0
714.00	57.3	0.0	0.30	9.69	3	0	0.0	0.0	0.000	0.000	0.0	3465	42.2	27.8	371.7	4.3	60.5	91.32	2.514	0.3685	0.0	2	0
715.00	57.7	0.0	0.40	9.70	3	0	0.0	0.0	0.000	0.000	0.0	3489	46.8	31.1	426.5	4.3	59.1	91.15	2.522	0.3699	0.0	2	0
716.00	58.1	0.1	0.43	9.72	3	0	0.0	0.0	0.000	0.000	0.0	3515	48.4	32.4	449.7	4.3	58.5	91.00	2.529	0.3714	0.0	2	310
717.00	58.8	0.0	0.47	9.73	3	3555	86.2	58.4	28.084	0.461	14.7	3555	-26.5	-17.9	12.8	4.2	69.4	******	2.529	0.3714	0.0	3	0
718.00	59.1	0.0	0.30	9.75	3	0	0.0	0.0	0.000	0.000	14.7	3572	43.5	29.6	401.3	4.2	59.7	91.07	2.536	0.3727	0.0	2	0
719.00	59.2	0.0	0.10	9.77	3	0	0.0	0.0	0.000	0.000	14.7	3578	34.5	23.5	307.0	4.2	62.0	90.93	2.541	0.3736	0.0	2	0
720.00	59.1	0.0	-0.10	9.78	3	0	0.0	0.0	0.000	0.000	14.7	3572	25.7	17.5	221.8	4.2	64.2	89.83	2.545	0.3741	0.0	2	0
721.00	58.8	0.0	-0.30	9.80	3	0	0.0	0.0	0.000	0.000	14.7	3553	16.7	11.3	142.7	4.2	66.1	86.70	2.548	0.3744	0.0	2	0
722.00	58.5	0.0	-0.30	9.82	3	0	0.0	0.0	0.000	0.000	14.7	3536	16.5	11.1	140.3	4.2	66.2	86.62	2.551	0.3748	0.0	2	0
723.00	58.1	0.0	-0.40	9.83	3	0	0.0	0.0	0.000	0.000	14.7	3512	11.9	7.9	102.0	4.3	67.1	82.96	2.553	0.3749	0.0	2	0
724.00	57.7	0.0	-0.40	9.85	3	0	0.0	0.0	0.000	0.000	14.7	3489	11.6	7.7	99.3	4.3	67.2	82.73	2.555	0.3751	0.0	2	0
725.00	57.3	0.0	-0.40	9.86	3	0	0.0	0.0	0.000	0.000	14.7	3465	11.4	7.5	96.7	4.3	67.3	82.49	2.557	0.3753	0.0	2	0
726.00	57.1	0.0	-0.20	9.88	3	0	0.0	0.0	0.000	0.000	14.7	3453	20.1	13.2	165.5	4.4	65.5	88.40	2.560	0.3757	0.0	2	0
727.00	56.8	0.0	-0.30	9.90	3	0	0.0	0.0	0.000	0.000	14.7	3436	15.5	10.1	127.7	4.4	66.5	86.12	2.562	0.3760	0.0	2	0
728.00	56.5	0.0	-0.30	9.91	3	0	0.0	0.0	0.000	0.000	14.7	3418	15.3	10.0	125.5	4.4	66.5	86.03	2.564	0.3762	0.0	2	0
729.00	56.2	0.0	-0.30	9.93	3	0	0.0	0.0	0.000	0.000	14.7	3401	15.2	9.8	123.4	4.4	66.6	85.93	2.567	0.3765	0.0	2	0
730.00	55.5	0.0	-0.70	9.94	3	0	0.0	0.0	0.000	0.000	0.0	3359	-2.8	-1.8	-6.1	4.5	69.9	85.93	2.567	0.3765	0.0	2	100
731.00	54.6	0.0	-0.90	9.96	3	0	0.0	0.0	0.000	0.000	0.0	3307	-12.1	-7.6	-68.7	4.6	71.4	85.93	2.565	0.3764	0.0	2	100
732.00	54.1	0.0	-0.50	9.97	3	0	0.0	0.0	0.000	0.000	0.0	3277	5.2	3.2	46.2	4.7	68.5	69.07	2.566	0.3764	0.0	2	0
733.00	53.7	0.0	-0.40	9.99	3	0	0.0	0.0	0.000	0.000	0.0	3253	9.4	5.8	75.1	4.7	67.8	79.86	2.568	0.3766	0.0	2	0
734.00	53.2	0.0	-0.50	10.00	3	0	0.0	0.0	0.000	0.000	0.0	3224	4.7	2.9	41.9	4.8	68.6	66.95	2.569	0.3767	0.0	2	0
735.00	52.9	0.0	-0.30	10.02	3	0	0.0	0.0	0.000	0.000	0.0	3206	13.3	8.1	101.4	4.8	67.1	84.63	2.571	0.3769	0.0	2	0
736.00	52.5	0.0	-0.40	10.03	3	0	0.0	0.0	0.000	0.000	0.0	3183	8.7	5.3	66.6	4.8	68.0	76.76	2.572	0.3770	0.0	2	0
737.00	52.0	0.0	-0.50	10.05	3	0	0.0	0.0	0.000	0.000	0.0	3153	4.0	2.4	36.5	4.9	68.8	63.65	2.573	0.3770	0.0	2	0
738.00	51.3	0.0	-0.70	10.06	3	0	0.0	0.0	0.000	0.000	0.0	3112	-5.1	-3.0	-22.5	5.0	70.2	63.65	2.573	0.3770	0.0	2	100
739.00	50.5	0.0	-0.80	10.08	3	0	0.0	0.0	0.000	0.000	0.0	3065	-9.9	-5.6	-51.4	5.1	71.0	63.65	2.572	0.3769	0.0	2	100
740.00	49.5	0.0	-1.00	10.09	3	0	0.0	0.0	0.000	0.000	0.0	3007	-19.2	-11.0	-103.7	5.2	72.3	63.65	2.570	0.3766	0.0	2	100
741.00	48.5	0.0	-1.10	10.10	3	0	0.0	0.0	0.000	0.000	0.0	2947	-19.7	-11.0	-104.6	5.3	72.3	63.65	2.568	0.3766	0.0	2	100
742.00	47.6	0.0	-0.90	10.12	3	0	0.0	0.0	0.000	0.000	0.0	2894	-15.7	-8.7	-81.4	5.5	71.7	63.65	2.566	0.3765	0.0	2	100
743.00	46.8	0.0	-0.80	10.13	3	0	0.0	0.0	0.000	0.000	0.0	2847	-11.7	-6.4	-58.4	5.6	71.1	63.65	2.565	0.3764	0.0	2	100
744.00	45.6	0.0	-1.20	10.14	3	0	0.0	0.0	0.000	0.000	0.0	2777	-29.8	-15.8	-150.6	5.8	73.4	63.65	2.562	0.3762	0.0	2	100
745.00	44.2	0.0	-1.40	10.15	3	0	0.0	0.0	0.000	0.000	0.0	2697	-39.2	-20.1	-191.6	6.0	74.5	63.65	2.558	0.3759	0.0	2	100
746.00	42.5	0.0	-1.70	10.17	3	0	0.0	0.0	0.000	0.000	0.0	2597	-53.0	-26.2	-246.6	6.3	75.8	63.65	2.553	0.3755	0.0	2	100
747.00	39.2	0.0	-3.30	10.18	3	0	0.0	0.0	0.000	0.000	0.0	2416	-124.3	-57.2	-495.7	6.9	82.1	63.65	2.542	0.3749	0.0	2	100
748.00	35.9	0.0	-3.30	10.19	3	0	0.0	0.0	0.000	0.000	0.0	2224	-125.4	-53.1	-465.9	7.8	81.3	63.65	2.532	0.3742	0.0	2	100
749.00	32.6	0.0	-3.30	10.20	3	0	0.0	0.0	0.000	0.000	0.0	2032	-126.3	-48.9	-434.5	8.9	80.5	63.65	2.522	0.3736	0.0	2	100
750.00	29.3	0.0	-3.30	10.21	3	0	0.0	0.0	0.000	0.000	0.0	1838	-127.2	-44.5	-401.2	10.3	79.6	63.65	2.514	0.3730	0.0	2	100
751.00	26.8	0.0	-2.50	10.21	3	0	0.0	0.0	0.000	0.000	0.0	1681	-93.0	-29.8	-280.6	11.9	76.6	63.65	2.508	0.3726	0.0	2	100
752.00	24.5	0.0	-2.30	10.22	1	0	0.0	0.0	0.000	0.000	0.0	4195	-32.4	-12.1	******	3.5	72.2	63.65	2.506	0.3725	-12.9	2	101

```
753.00 21.5 0.0-3.00  10.23 1   0   0.0  0.0  0.000  0.000   0.0 3826 -44.1 -32.1-290.5   3.9  77.0 63.65  2.499 0.3721   0.0 2100
754.00 19.5 0.0-2.00  10.23 1   0   0.0  0.0  0.000  0.000   0.0 3446 -27.7 -18.2-169.8   4.4  74.0 63.65  2.496 0.3718   0.0 2100
755.00 17.4 0.0-2.10  10.24 1   0   0.0  0.0  0.000  0.000   0.0 3101 -29.5 -17.4-164.6   5.0  73.8 63.65  2.493 0.3716   0.0 2100
756.00 15.1 0.0-2.30  10.24 1   0   0.0  0.0  0.000  0.000   0.0 2728 -32.9 -17.1-163.5   5.9  73.6 63.65  2.490 0.3713   0.0 2100
757.00 12.4 0.0-2.70  10.25 1   0   0.0  0.0  0.000  0.000   0.0 2304 -39.6 -17.4-167.9   7.4  73.8 63.65  2.486 0.3711   0.0 2100
758.00  9.7 0.0-2.70  10.25 1   0   0.0  0.0  0.000  0.000   0.0 1852 -39.7 -14.6-137.7  10.2  73.0 63.65  2.484 0.3709   0.0 2100
759.00  7.0 0.0-2.70  10.25 1   0   0.0  0.0  0.000  0.000   0.0 1650   0.9   0.3   6.3  12.2  69.4 63.65  2.484 0.3709-10.6 2100
760.00  5.0 0.0-2.00  10.25 1   0   0.0  0.0  0.000  0.000   0.0 1650   0.9   0.3   6.3  12.2  69.4 63.65  2.484 0.3709 -5.5 2100
761.00  3.3 0.0-1.70  10.25 1   0   0.0  0.0  0.000  0.000   0.0 1650   0.9   0.3   6.3  12.2  69.4 63.65  2.485 0.3710 -3.1 2100
762.00  2.0 0.0-1.30  10.26 1   0   0.0  0.0  0.000  0.000   0.0 1650   0.9   0.3   6.3  12.2  69.4 63.65  2.485 0.3710 -1.5 2100
763.00  0.7 0.0-1.30  10.26 1   0   0.0  0.0  0.000  0.000   0.0 1650   0.9   0.3   6.3  12.2  69.4 63.65  2.485 0.3710 -0.7 2100
764.00  0.0 0.0-0.70  10.26 1   0   0.0  0.0  0.000  0.000   0.0 1650   0.9   0.3   6.3  12.2  69.4 63.65  2.486 0.3711 -0.1 2100
765.00  0.0 0.0 0.00  10.26 1   0   0.0  0.0  0.000  0.000   0.0 1650   0.9   0.3   6.3  12.2  69.4 16.97  2.486 0.3711  0.0 2  5
SUMMARY STATISTICS FOR:
```

EPA HIGHWAY DRIVING CYCLE (765 SECONDS)

MPG	MPH	MILES	GALLONS	NSHFT	POS ENG BHPHR	NEG ENG BHPHR	POS MOT BHPHR	NEG MOT BHPHR	BRAKE BHPHR
621.956	48.264	10.26	0.016	3	0.239	0.000	3.164	-0.343	-0.010

KM/L	KM/HR	KM	LITERS	POS ENG KWHR	NEG ENG KWHR	POS MOT KWHR	NEG MOT KWHR	BRAKE KWHR
264.421	77.674	16.51	0.062	0.179	0.000	2.360	-0.256	-0.007

INITIAL S	FINAL S	BATTERY KWHR	REGEN KWHR
0.0000	0.3711	2.486	-0.165

SUMMARY OUTPUT INFORMATION
FROM CARSIM

HOT START LA-4 DRIVING CYCLE (1372 SECONDS)
EQUIVALENT TO BAGS 2 AND 3 OF THE EPA URBAN CYCLE

MPG	MPH	MILES	GALLONS	NSHFT	POS ENG BHPHR	NEG ENG BHPHR	POS MOT BHPHR	NEG MOT BHPHR	BRAKE HPHR
299.842	19.537	7.45	0.025	13	0.353	0.000	2.792	-1.051	-0.153

KM/L	KM/HR	KM	LITERS	POS ENG KWHR	NEG ENG KWHR	POS MOT KWHR	NEG MOT KWHR	BRAKE KWHR
127.476	31.442	11.98	0.094	0.263	0.000	2.082	-0.783	-0.114

INITIAL S	FINAL S	BATTERY KWHR	REGEN KWHR
0.0300	0.1812	1.809	-0.649

EPA HIGHWAY DRIVING CYCLE (765 SECONDS)

MPG	MPH	MILES	GALLONS	NSHFT	POS ENG BHPHR	NEG ENG BHPHR	POS MOT BHPHR	NEG MOT BHPHR	BRAKE HPHR
380.903	48.262	10.26	0.027	3	0.387	0.003	3.220	-0.406	-0.011

KM/L	KM/HR	KM	LITERS	POS ENG KWHR	NEG ENG KWHR	POS MOT KWHR	NEG MOT KWHR	BRAKE KWHR
161.939	77.670	16.50	0.102	0.288	0.000	2.401	-0.303	-0.008

INITIAL S	FINAL S	BATTERY KWHR	REGEN KWHR
0.3000	0.2936	2.536	-0.208

SAE J227A (B) ELECTRIC VEHICLE DRIVING CYCLE

```
   TIME  VEL  DV  ACC   DIST J   BE   TE BHPE  LB/HR  BSFC  MPG  HR  TH  BHPB  IARM  IFLD  EB  RPPM  KWHR  S  BHPB B CUR
```

SUMMARY STATISTICS FOR:
SAE J227A (B) ELECTRIC VEHICLE DRIVING CYCLE

MPG	MPH	MILES	GALLONS	NSHFT	POS ENG BHPHR	NEG ENG BHPHR	POS MOT BHPHR	NEG MOT BHPHR	BRAKE BPHR
0.000	10.133	0.20	0.000	0	0.000	0.000	0.077	-0.019	-0.009

KM/L	KM/HR	KM	LITERS	POS ENG KWHR	NEG ENG KWHR	POS MOT KWHR	NEG MOT KWHR	BRAKE KWHR
0.000	16.334	0.33	0.000	0.000	0.003	0.058	-0.014	-0.006

INITIAL S	FINAL S	BATTERY KWHR	REGEN KWHR
0.0000	0.0043	0.068	-0.012

APPENDIX B

MISSIM
MINICARS' COMPUTER PROGRAM FOR PETROLEUM AND ELECTRICAL CONSUMPTION EVALUATION THROUGH A SPECIFIED MISSION

PROGRAM LISTING
FOR MISSIM

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C     INTERMEDIATE PROGRAM BETWEEN CARSIM AND LCC
      DIMENSION X(20),P(20),V(20),Y(20,5),ED(10),DE(10),RANGE(20),
     1SUME(20),SUMF(20),SUMX(20),SUMY(20)
      NIN=5
      NOUT=6
      DO 98 I=1,20
      X(I)=0.
      P(I)=0.
      V(I)=0.
      SUME(I)=0.
      SUMF(I)=0.
      SUMX(I)=0.
      SUMY(I)=0.
      DO 99 J=1,5
   99 Y(I,J)=0.
   98 CONTINUE
C     N IS THE NUMBER OF AVERAGE TRIP LENGTHS, MAX=20
      READ(NIN,1) N
    1 FORMAT(I5)
      DO 2 I=1,N
C     X=AVERAGE TRIP LENGTH,KM ; P=PROBABILITY OF OCCURRENCE OF X
      READ(NIN,3) X(I),P(I)
    3 FORMAT(8F10.0)
      IF(X(I).LE.1.) V(I)=8.8*X(I)
      IF(X(I).GT.1.0.AND.X(I).LE.2.0) V(I)=4.6*X(I)+4.2
      IF(X(I).GT.2.0.AND.X(I).LE.3.0) V(I)=4.0*X(I)+5.4
      IF(X(I).GT.3.0.AND.X(I).LE.6.0) V(I)=2.6*X(I)+9.6
      IF(X(I).GT.6.0.AND.X(I).LE.10.0)V(I)=1.75*X(I)+14.7
      IF(X(I).GT.10.0.AND.X(I).LE.16.0)V(I)=1.23*X(I)+19.9
      IF(X(I).GT.16.0.AND.X(I).LE.30.42)V(I)=1.05*X(I)+22.78
      IF(X(I).GT.30.42.AND.X(I).LE.56.55)V(I)=0.8744*X(I)+28.12
    2 IF(X(I).GT.56.55) V(I)=77.57
C     VSAE=AVERAGE VELOCITY,KM/HR FOR SAE J227A(B)
C     XSAE=LENGTH,KM FOR SAE J227A(B)
C     VFUDC=AVERAGE VELOCITY,KM/HR FOR FUDC
C     XFUDC=LENGTH,KM FOR FUDC
C     VFHDC=AVERAGE VELOCITY,KM/HR FOR FHDC
C     XFHDC=LENGTH,KM FOR FHDC
      READ(NIN,3) VSAE,XSAE,VFUDC,XFUDC,VFHDC,XFHDC
      DO 4 I=1,N
      IF(V(I).GT.VSAE) GO TO 100
      Y(I,1)=X(I)
      GO TO 4
  100 IF(V(I).GT.VFUDC) GO TO 101
      R=((1./V(I))-(1./VFUDC))/((1./VSAE)-(1./VFUDC))
      Y(I,1)=0.5*R*X(I)
      Y(I,2)=(1.-R)*X(I)
      Y(I,5)=Y(I,1)
      GO TO 4
  101 IF(V(I).GT.VFHDC) GO TO 102
      R=((1./V(I))-(1./VFHDC))/((1./VFUDC)-(1./VFHDC))
      Y(I,2)=0.5*R*X(I)
      Y(I,3)=(1.-R)*X(I)
      Y(I,4)=Y(I,2)
      GO TO 4
```

```
  102 Y(I,3)=X(I)
    4 CONTINUE
C     EDSAES=ELECTRIC MODE TOPPED BY DIESEL,SAE J227A(B),DELTA S/CYCLE
C     EDSAEL=ELECTRIC MODE TOPPED BY DIESEL,SAE J227A(B),LITERS/CYCLE
C     EDUS=ELECTRIC MODE TOPPED BY DIESEL,FUDC,DELTA S/CYCLE
C     EDUL=ELECTRIC MODE TOPPED BY DIESEL,FUDC,LITERS/CYCLE
C     EDHS=ELECTRIC MODE TOPPED BY DIESEL,FHDC,DELTA S/CYCLE
C     EDHL=ELECTRIC MODE TOPPED BY DIESEL,FHDC,LITERS/CYCLE
C     DESAES=DIESEL MODE TOPPED BY ELECTRIC,SAE J227A(B),DELTA S/CYCLE
C     DESAEL=DIESEL MODE TOPPED BY ELECTRIC,SAE J227A(B),LITERS/CYCLE
C     DEUS=DIESEL MODE TOPPED BY ELECTRIC,FUDC,DELTA S/CYCLE
C     DEUL=DIESEL MODE TOPPED BY ELECTRIC,FUDC,LITERS/CYCLE
C     DEHS=DIESEL MODE TOPPED BY ELECTRIC,FHDC,DELTA S/CYCLE
C     DEHL=DIESEL MODE TOPPED BY ELECTRIC,FHDC,LITERS/CYCLE
      READ(NIN,3)EDSAES,EDSAEL,EDUS,EDUL,EDHS,EDHL
      READ(NIN,3)DESAES,DESAEL,DEUS,DEUL,DEHS,DEHL
C     INITIAL STATE OF CHARGE CORRECTIONS
      EDSAES=1.02*EDSAES
      EDUS=1.0195*EDUS
      EDUL=1.0642*EDUL
      EDHS=1.009*EDHS
      EDHL=1.2816*EDHL
C     BETA=AVERAGE NUMBER OF TRIPS PER DAY
C     CUTOFF=BATTERY DISCHARGE CUTOFF VALUE
C     BENER=BATTERY ENERGY,KW-HR
C     CHEFF=CHARGER EFFICIENCY
      READ(NIN,3)BETA,CUTOFF,BENER,CHEFF
      WRITE(NOUT,34)
   34 FORMAT(1H0,'SAEJ227A(B)',8X,'FUDC',11X,'FHDC',11X,
     1'FUDC',7X,'SAEJ227A(B)')
      DO 40 I=1,N
   40 WRITE(NOUT,33)(Y(I,J),J=1,5)
   33 FORMAT(1H0,5(F10.4,5X))
      WRITE(NOUT,35)
      WRITE(NOUT,36)
   35 FORMAT(1H0,'AV. TRIP',3X,'AV. DAILY',2X,'AV. SPEED',2X,
     1'ELECTRIC',3X,'BATT. CONS',1X,'ELEC. CONS',1X,
     2'ELEC. ECON',1X,'FUEL CONS',2X,'FUEL ECON',2X,'PROB. OF')
   36 FORMAT(1H ,'LENGTH,KM',2X,'TRAVEL,KM',4X,'KM/HR',4X,
     1'DIST ,KM',3X,'DEL S/DAY',2X,'KW-HR/DAY',2X,
     2'KM/KW-HR',3X,'LITERS/DAY',1X,'KM/LITER',3X,'TRIP L.')
      DO 5 I=1,N
      ED(1)=EDSAES/(XSAE*10.)
      ED(2)=EDUS/(XFUDC*10.)
      ED(3)=EDHS/(XFHDC*10.)
      ED(4)=ED(2)
      ED(5)=ED(1)
      ED(6)=EDSAEL/(XSAE*10.)
      ED(7)=EDUL/(XFUDC*10.)
      ED(8)=EDHL/(XFHDC*10.)
      ED(9)=ED(7)
      ED(10)=ED(6)
      DE(1)=DESAES/(XSAE*10.)
      DE(2)=DEUS/(XFUDC*10.)
      DE(3)=DEHS/(XFHDC*10.)
      DE(4)=DE(2)
      DE(5)=DE(1)
      DE(6)=DESAEL/(XSAE*10.)
      DE(7)=DEUL/(XFUDC*10.)
      DE(8)=DEHL/(XFHDC*10.)
      DE(9)=DE(7)
      DE(10)=DE(6)
      DIFF=0.
      IEND=BETA
      A=IEND
      IF(A.LT.BETA)IEND=IEND+1
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
      IF(A.LT.BETA)DIFF=BETA-A
      KOUNT=0
      JEND=X(I)*BETA*10.
      DO 69 I1=1,JEND
      KOUNT=KOUNT+1
      SUME(I)=0.
      SUMF(I)=0.
      SUMX(I)=0.
      SUMY(I)=0.
      ICOUNT=0
      DO 70 I2=1,IEND
      FAC=1.
      IF(I2.EQ.IEND)FAC=DIFF
      DO 71 I3=1,5
      KEND=Y(I,I3)*FAC*10.
      IF(KEND.EQ.0) GO TO 71
      DO 72 K=1,KEND
      ICOUNT=ICOUNT+1
      IF(ICOUNT.LE.KOUNT)SUME(I)=SUME(I)+ED(I3)
      IF(ICOUNT.LE.KOUNT)SUMF(I)=SUMF(I)+ED(I3+5)
      IF(ICOUNT.GT.KOUNT)SUMX(I)=SUMX(I)+DE(I3)
   72 IF(ICOUNT.GT.KOUNT)SUMY(I)=SUMY(I)+DE(I3+5)
   71 CONTINUE
   70 CONTINUE
      A=SUME(I)+SUMX(I)
      IF(A.GT.CUTOFF) GO TO 500
   69 CONTINUE
  500 A=KOUNT
      D=0.
      B=(SUME(I)+SUMX(I))*BENER/CHEFF
      RANGE(I)=0.1*A
      A=X(I)*BETA
      C=A/B
      AA=SUMF(I)+SUMY(I)
      IF(AA.GT.0.) D=A/AA
      SS1=SUME(I)+SUMX(I)
      SS2=SUMF(I)+SUMY(I)
      WRITE(NOUT,30)X(I),A,V(I),RANGE(I),SS1,B,C,SS2,D,P(I)
   30 FORMAT(1H0,10(F10.4,1X))
    5 CONTINUE
      E=0.
      VEL=0.
      XAV=0.
      RAN=0.
      T1=0.
      T2=0.
      T3=0.
      T4=0.
      A=0.
      B=0.
      DO 6 I=1,N
      XAV=XAV+X(I)*P(I)
      VEL=VEL+V(I)*P(I)
      RAN=RAN+RANGE(I)*P(I)
      E=E+(SUME(I)+SUMX(I))*P(I)
      B=B+((SUME(I)+SUMX(I))*BENER/CHEFF)*P(I)
      T1=T1+(SUME(I)*BENER/CHEFF)*P(I)
      T2=T2+SUME(I)*P(I)
      T3=T3+(SUMX(I)*BENER/CHEFF)*P(I)
      T4=T4+SUMY(I)*P(I)
    6 A=A+(SUMF(I)+SUMY(I))*P(I)
      TFUEL=365.*A
      TELEC=365.*B
      XXAV=XAV*BETA
      C=XXAV/B
      D=XXAV/A
```

```
      WRITE(NOUT,31)
      WRITE(NOUT,30)XAV,XXAV,VEL,HAN,E,B,C,A,D
   31 FORMAT(1H0,'WEIGHTED AVERAGES')
      WRITE(NOUT,32) TELEC,TFUEL
   32 FORMAT(1H0,'ELEC. CONS. PER ANNUM=',F10.2,' KW-HR',
     110X,'FUEL CONS. PER ANNUM=',F10.2,' LITERS')
      WRITE(NOUT,39)
      WRITE(NOUT,137)
  137 FORMAT(1H0,6X,'KW',14X,'KW-HR/DAY',9X,'LITERS/DAY',10X,'KW-HR/DAY'
     1,9X,'LITERS/DAY')
      DO 171 I=1,N
      SUME(I)=SUME(I)*BENER/CIEFF
      SUMX(I)=SUMX(I)*BENER/CIEFF
  171 WRITE(NOUT,37)X(I),SUME(I),SUMF(I),SUMX(I),SUMY(I),P(I)
      WRITE(NOUT,31)
      WRITE(NOUT,38)XAV,T1,T2,T3,T4
      T1=T1/XAV
      T2=T2/XAV
      T3=T3/XAV
      T4=T4/XAV
      WRITE(NOUT,133)
  138 FORMAT(1H0,6X,'KW',14X,'KW-HR/KM ',9X,'LITERS/KM ',10X,'KW-HR/KM '
     1,9X,'LITERS/KM')
      WRITE(NOUT,38)XAV,T1,T2,T3.T4
   39 FORMAT(1H1)
   37 FORMAT(1H0,'X=',F10.4,5X,'ED1=',F10.4,5X,'ED2=',F10.4,5X,
     1'DE1=',F10.4,5X,'DE2=',F10.4,5X,'P(X)=',F10.4)
   38 FORMAT(1H0,2X,F10.4,4(9X,F10.4))
      STOP
      END
COMMAND/
```

SAMPLE PROGRAM INPUT
FOR MISSIM

```
     8
2.31      0.25
5.98      0.25
12.10     0.25
18.90     0.10
25.70     0.05
37.67     0.05
61.74     0.04
99.42     0.01
16.3      0.326     31.5      12.05     77.56     16.40
0.0050    0.0       0.2239    0.057     0.3033    0.056
0.0       0.024     0.0010    0.821     0.0015    0.792
3.74      0.8       8.40      0.79
COMMAND?
```

SAMPLE PROGRAM OUTPUT
FOR MISSIM

SAEJ227A(B)	FUDC	FHDC	FUDC	SAEJ227A(B)
2.3100	0.0	0.0	0.0	0.0
0.8099	4.3602	0.0	0.0	0.8099
0.0	5.0885	1.9231	5.0885	0.0
0.0	5.2968	8.3064	5.2968	0.0
0.0	4.9083	15.8834	4.9083	0.0
0.0	3.4812	30.7077	3.4812	0.0
0.0	0.0	61.7400	0.0	0.0
0.0	0.0	99.4200	0.0	0.0

AV. TRIP LENGTH,KM	AV. DAILY TRAVEL,KM	AV. SPEED KM/HR	ELECTRIC DIST ,KM	BATT. CONS DEL S/DAY	ELEC. CONS KW-HR/DAY	ELEC. ECON KM/KW-HR	FUEL CONS LITERS/DAY	FUEL ECON KM/LITER	PROB. OF TRIP L.
2.3100	8.6394	14.6400	8.6000	0.1345	1.4305	6.0393	0.0	0.0	0.2500
5.9800	22.3652	25.1480	22.3000	0.3957	4.2076	5.3154	0.0810	275.9590	0.2500
12.1000	45.2540	34.7830	42.4000	0.8013	8.5206	5.3111	0.3518	128.6212	0.2500
18.9000	70.6860	42.6250	42.4000	0.8009	8.5158	8.3005	1.7972	39.3309	0.1000
25.7000	96.1180	49.7650	42.4000	0.8000	8.5066	11.2992	3.2035	30.0043	0.0500
37.6700	140.8858	61.0586	42.3000	0.8010	8.5172	16.5413	5.2207	26.9860	0.0500
61.7400	230.9076	77.5700	42.0000	0.8010	8.5167	27.1124	9.2953	24.8414	0.0400
99.4200	371.8306	77.5700	41.3000	0.8009	8.5156	43.6647	16.1341	23.0462	0.0100
WEIGHTED AVERAGES									
13.6198	50.9380	32.3249	28.8930	0.5331	5.6683	8.9865	1.2423	41.0030	

ELEC. CONS. PER ANNUM= 2068.93 KW-HR FUEL CONS. PER ANNUM= 453.44 LITERS

	KM		KW-HR/DAY		LITERS/DAY		KW-HR/DAY		LITERS/DAY		
X=	2.3100	EDI=	1.4305	ED2=	0.0	DE1=	0.0	DE2=	0.0	P(X)=	0.2500
X=	5.9800	EDI=	4.2076	ED2=	0.0810	DE1=	0.0	DE2=	0.0	P(X)=	0.2500
X=	12.1000	EDI=	8.5188	ED2=	0.2033	DE1=	0.0019	DE2=	0.1431	P(X)=	0.2500
X=	18.9000	EDI=	8.4992	ED2=	0.2025	DE1=	0.0257	DE2=	1.5947	P(X)=	0.1000
X=	25.7000	EDI=	8.4560	ED2=	0.1952	DE1=	0.0499	DE2=	3.0083	P(X)=	0.0500
X=	[illegible]	EDI=	[illegible]	ED2=	[illegible]	DE1=	[illegible]	DE2=	[illegible]	P(X)=	[illegible]

ORIG... OF POOR QUALITY

```
X=   61.7400    EDI=    8.3332    ED2=    0.1838    DE1=    0.1035    DE2=    9.1115    P(X)=    0.0400
X=   99.4200    EDI=    8.1943    ED2=    0.1807    DE1=    0.3213    DE2=   15.9534    P(X)=    0.0100
WEIGHTED AVERAGES
      13.6198            5.6475             0.1212            0.0208            1.1211
       KM              KW-HR/KM           LITERS/KM          KW-HR/KM          LITERS/KM
      13.6198            0.4147             0.0089            0.0015            0.0823
COMMAND?
```

APPENDIX C

PRESENT-VALUE LIFE CYCLE COST ANALYSIS COMPUTER PROGRAM FOR A NEAR TERM HYBRID VEHICLE

PRESENT-VALUE LIFE CYCLE COST ANALYSIS COMPUTER PROGRAM FOR A NEAR TERM HYBRID VEHICLE

In this computer program life cycle costs (LCCs) are divided into five groups: the first group calculates the manufacturing and acquisition costs for a Near Term Hybrid Vehicle (NTHV); the second deals with the research and development costs; the third concentrates on the propulsion system maintenance costs; the fourth calculates the total operating costs for an NTHV; and the fifth group combines all the previously detailed LCC items and does a present-value analysis for each item. Finally, by knowing the present value of total LCC for an NTHV, the program compares the results with the LCC of a conventional internal combustion engine (ICE) vehicle and determines the "net benefit" per NTHV.

The LCC analysis computer program is written in Fortran IV. The flow chart and the listing of the computer program are presented at the end of this report.

MANUFACTURING AND VEHICLE ACQUISITION COSTS

The manufacturing cost of a vehicle component or system is obtained from its unit cost estimating relationship. This relationship is considered as a second order polynomial:

$$\text{UNIT COST} = f(W_c) = A_o + A_1 \times W_c + A_2 \times W_c \times W_c \quad , \qquad (1)$$

where W_c is the vehicle curb weight, which can be replaced by $\ln(W_c)$ or $\sin(W_c)$, if desired. Also the unit cost estimating relationship can be extended to higher order polynomials and to other functional relationships, if necessary. The result of Equation 1 is the manufacturing unit cost for the vehicle component or system, for example, $/kg or $/kW. The unit cost is multiplied with the appropriate characteristic of the component or system, (weight of the system, power of the system, etc.) in order to obtain the manufacturing cost.

The vehicle can be divided into any number of components and systems. The input data requirements for this section of the program are the component's or system's name, weight and, if necessary, its appropriate characteristic. Also, the coefficients, the functional form and the units of Equation 1 are to be inputted for each component and system. The last manufacturing unit cost estimating relationship has to be for the vehicle assembly cost, whose appropriate characteristic is assumed to be the vehicle curb weight that is determined in the program.

After the manufacturing costs are calculated, the mark-up factor for the vehicle is analyzed using an estimating relationship similar to Equation 1, but now the independent variable is the total manufacturing cost. The mark-up factor is multiplied with the total manufacturing cost in order to obtain the purchase price of the vehicle.

One then inputs the financing terms (such as the interest rate and the finance duration), the sales tax and the salvage value at the end of ten years (as percentages of the vehicle purchase price), and the discount rate for the present-value calculations. The cost of financing the vehicle purchase price is calculated by the formula:

$$\text{INTEREST} = P \times \left\{ i \times n \times [1-(1+i)^{-n}]^{-1} - 1 \right\} \quad , \qquad (2)$$

where P is the purchase price, i is the interest rate, and n is the finance duration in years.

All the present-value calculations in this economic analysis are performed for each year, as follows:

$$\text{PRESENT-VALUE} = S \ / \ (1 + j)^{m} \quad , \qquad (3)$$

where S is the value to be discounted in the mth year after 1985 and j is the discount rate.

The battery replacement costs are calculated in this section because they are treated similarly to the vehicle manufacturing costs. The battery manufacturing cost is obtained with an estimating relationship having the form of Equation 1, but the independent variable is the total battery weight that has to be replaced periodically.

The mark-up factor for the batteries is also analyzed with an estimating relationship similar to Equation 1. This time the independent variable is the battery manufacturing cost, and the mark-up factor is multiplied by the battery manufacturing cost in order to obtain the purchase price for the replacement batteries.

The battery replacement financing terms, such as the interest rate and the finance duration (which has to be less than or equal to the life of the batteries) are inputted. The sales tax and the salvage value are inputted as percentages of the battery replacement purchase price. Then the cost of financing the battery replacement is calculated by using Equation 2 with the appropriate financing parameters.

RESEARCH AND DEVELOPMENT COSTS

The research and development costs can be estimated by dividing them into any number of elements. (This analysis can be omitted, if desired.) Each element's cost is calculated according to the formula:

$$R + D \text{ ELEMENT COST} = (T \times R + C)(1 + L) \quad , \tag{4}$$

where T is the research and development element's man-hour estimate in hours, R is the man-hour composite rate in \$/hr, C is the man-hour related costs in dollars, and L is the contractor's profit percentage.

For each research and development element, the values of T, R, C and L have to be inputted. In the present-value calculations of the total research and development cost, equal annual costs are assumed, and the total research and development cost is divided into the number of research and development years in order to obtain the annual research and development cost. The research and development cost amortization duration (in years) and the annual vehicle production rate have to be inputted in order to be able to calculate the research and development amortization per NTHV vehicle.

PROPULSION SYSTEM MAINTENANCE COSTS

The propulsion system maintenance costs are a portion of the operating cost. The propulsion system maintenance costs can be estimated by dividing them into any number of elements. First, the annual driven distances of the vehicle have to be inputted for ten years. Then one has to input each propulsion system maintenance cost element's name, scheduled maintenance interval in kilometers, mean time to repair, mean time to replace, mean time to inspect (all in hours), labor rate in $/hr, and parts cost per maintenance interval in dollars. The program calculates the lifetime total cost of each element and the total propulsion system maintenance cost for each year.

TOTAL OPERATING COSTS

The total operating costs are divided into four subsystems – energy, maintenance and repair, battery replacement and other operating costs. The battery replacement costs are calculated in the manufacturing cost group, and the propulsion system maintenance costs are determined in their own group. The total number of energy, maintenance and repair, and other operating cost elements that have to be treated in this section, has to be less than or equal to 20.

For each energy cost element, its name, its forecasted unit costs in 1978 dollars for each year, its consumption rate (e.g., km/kW-hr, km/ℓ) have to be inputted. The first energy cost element has to be petroleum, which will later be used in the net benefit calculations.

For each maintenance and repair cost element, its name and its unit cost in $/km have to be inputted. Also, for each other operating cost element (such as insurance, accessories, and tire replacement), its name and its unit cost in $/km have to be inputted. All the input dollar values have to be in 1978 dollars.

The program writes out the operating cost elements in detail and calculates the total operating costs for each year.

PRESENT-VALUE OF TOTAL LIFE CYCLE COSTS

The vehicle acquisition costs, the operating costs, and the research and development cost amortization are discounted to present value, and the present value of the total LCC for an NTHV is calculated. Then, for the reference conventional ICE vehicle, present values of the petroleum energy costs and the total LCC (which are calculated using the same methodology as above) have to be inputted. The BENEFIT per NTHV is defined as the savings in petroleum consumption,

$$BENEFIT = PET_{ICE} - PET_{NTHV} \quad , \tag{5}$$

where PET_{ICE} is the petroleum energy cost for an ICE vehicle and PET_{NTHV} is the petroleum energy cost for an NTHV. The cost of accruing this benefit per NTHV is calculated by the formula:

$$COST = (LCC - PET)_{NTHV} - (LCC - PET)_{ICE} \quad . \tag{6}$$

As a result, the NET BENEFIT per NTHV becomes the difference between the BENEFIT and the COST.

COMPUTER PROGRAM INPUT PROCEDURE

1.1 Title of the Project

TITLE = Title of the project

Variable Name	Dimension	Limit	Format
TITLE	-	Max. 80 characters	80A1

1.2 Computer Run Data

NORUN = Computer run number
NOSYS = NTHV system package number
NYEAR = Dollar value year
JYEAR = First production and marketing year
NPROD = Number of production years
NNUAL = Annual production rate
DATE = Computer run date

Variable Name	Dimension	Limit	Format
NORUN	-	-	I10
NOSYS	-	-	I10
NYEAR	-	-	I10
JYEAR	-	-	I10
NPROD	Years	-	I10
NNUAL	Veh/Year	-	I10
DATE	-	Max. 20 characters	20A1

2.1 Number of Manufacturing Cost Items

N = Number of manufacturing cost items + 1
("+1" refers to the "Vehicle Assembly Cost"
and it should be the last item)

Variable Name	Dimension	Limit	Format
N	-	Max. 49	I5

2.2 Vehicle Manufacturing Costs

SNAME = Manufacturing cost item name

WEIGHT = Component or system weight in kg

AO = Constant coefficient for the unit manufacturing cost estimating relationship (e.g., UNIT COST = A0 + A1 × W_c + A2 × W_c × W_c, where W_c is the vehicle's curb weight in kg)

A1 = First degree coefficient for the unit manufacturing cost estimating relationship

A2 = Second degree coefficient for the unit manufacturing cost estimating relationship

UNITS = Dimension of the unit manufacturing cost (e.g., $/kW)

KODFUN = Function code for the unit manufacturing cost estimating relationship
KODFUN = 0 means $W_c = W_c$
KODFUN = 1 means $W_c = \ln(W_c)$
KODFUN = 2 means $W_c = \sin(W_c)$

XUNIT = If the dimension of the unit manufacturing cost is different than $/kg such as $/kW, then XUNIT is component's kW value. If the dimension of the unit manufacturing cost is $/kg, then XUNIT = 0.

Variable Name	Dimension	Limit	Format
SNAME	-	Max. 30 characters	30A1
WEIGHT		-	F5.0
A0	Unit cost dim.	-	E11.4
A1	$\frac{\text{Unit cost dim.}}{W_c}$	-	E11.4
A2	$\frac{\text{Unit cost dim.}}{W_c \times W_c}$	-	E11.4
UNITS	-	Max. 6 characters	6A1
KODFUN	-	0, 1, or 2	I1
XUNIT	$/Unit cost dim.	-	F5.0

Repeat 2.2 N Times

2.3 Vehicle Mark-up Factor

SNAME = Mark-up factor for the vehicle
DUMMY = A dummy variable
A0 = Constant coefficient for the mark-up factor equation

(Y = A0 + A1 × X + A2 × X × X, where

X = Total manufacturing cost, if KODFUN = 0
X = ln (total manufacturing cost), if KODFUN = 1
X = sin (total manufacturing cost), if KODFUN = 2

A1 = First degree coefficient for the mark-up factor equation
A2 = Second degree coefficient for the mark-up factor equation
UNITS = (Acquisition cost, $)/(Total manufacturing cost, $)
KODFUN = Function code for the mark-up factor equation

Variable Name	Dimension	Limit	Format
SNAME	-	Max. 30 characters	30A1
DUMMY	-	-	F5.0
A0	-	-	E11.4
A1	1/$,if KODFUN=0	-	E11.4
A2	$1/\$^2$,if KODFUN=0	-	E11.4
UNITS	-	Max. 6 characters	6A1
KODFUN	-	0, 1, or 2	I1

2.4 Vehicle Sale and Salvage Conditions

TAX = Vehicle sales tax
FAIZ = Interest rate
AY = Finance period in months
SALVA1 = Salvage value of the vehicle given as the percentage of the purchase price
DISCNT = Present-value discount rate

Variable Name	Dimension	Limit	Format
TAX	-	0. to 1.0	F10.0
FAIZ	-	0. to 1.0	F10.0
AY	Month	Max. 120 months	F10.0
SALVA1	-	0. to 1.0	F10.0
DISCNT	-	0. to 1.0	F10.0

3.1 Replacement Battery Manufacturing Cost

SNAME = Replacement battery data

WEIGHT = Weight of the battery to be replaced periodically

A0 = Constant coefficient for the battery manufacturing unit cost equation (Y = A0 + A1 × X + A2 × X × X), where

X = WEIGHT, if KODFUN = 0
X = ln (WEIGHT), if KODFUN = 1
X = sin (WEIGHT), if KODFUN = 2

A1 = First degree coefficient for the battery manufacturing unit cost equation

A2 = Second degree coefficient for the battery manufacturing unit cost equation

UNITS = $, Manufacturing cost of batteries = Y × WEIGHT

KODFUN = Function code for the battery manufacturing unit cost equation

Variable	Dimension	Limit	Format
SNAME	-	Max. 30 characters	30A1
WEIGHT	kg	-	F5.0
A0	$/kg	-	E11.4
A1	$/kg^2, if KODFUN=0	-	E11.4
A2	$/kg^3, if KODFUN=0	-	E11.4
UNITS	-	Max. 6 characters	6A1
KODFUN	-	0, 1, or 2	I1

3.2 Battery Mark-up Factor

SNAME = Mark-up factor for the replacement batteries
BLIFE = Battery life in years
A0 = Constant coefficient for the mark-up factor equation
    ($Y = A0 + A1 \times X + A2 \times X \times X$), where
    X = Battery manuf. cost, if KODFUN = 0
    X = ln (battery manuf. cost), if KODFUN = 1
    X = sin (battery manuf. cost), if KODFUN = 2
A1 = First degree coefficient for the mark-up factor equation
A2 = Second degree coefficient for the mark-up factor equation
UNITS = None, Acquisition cost = Y × Battery manuf. cost
KODFUN = Function code for the mark-up factor equation

Variable Name	Dimension	Limit	Format
SNAME	-	Max. 30 characters	30A1
BLIFE	Year	Max. 10 years	F5.0
A0	-	-	E11.4
A1	1/\$,if KODFUN=0	-	E11.4
A2	$1/\$^2$, if KODFUN=0	-	E11.4
UNITS	-	Max. 6 characters	6A1
KODFUN	-	0, 1, or 2	I1

3.3 Battery Replacement and Salvage Conditions

TAX = Battery replacement sale tax
FAIZ = Interest rate
AY = Finance period in months which should be less than or equal to the life of the batteries

SALVA1 = Salvage value of the batteries as a percentage of the battery purchase price

Variable Name	Dimension	Limit	Format
TAX	-	0. to 1.0	F10.0
FAIZ	-	0. to 1.0	F10.0
AY	Month	Max.=BLIFE × 12	F10.0
SALVA1	-	0. to 1.0	F10.0

4.1 Research and Development Cost Data

N = Number of research and development cost items

NRDVEH = Number of research and development prototype vehicles to be produced

NRDYR = Number of research and development years

IAMORT = Number of research and development cost amortization years

DISRD = Research and development discount rate

Variable Name	Dimension	Limit	Format
N	-	-	I5
NRDVEH	-	-	I5
NRDYR	Year	-	I5
IAMORT	Year	-	I5
DISRD	-	0. to 1.0	F5.0

4.2 Research and Development Item Data

SNAME = Research and development cost item name

HRMAN = Man-hours in hrs

RATE = Composite man-hour rate in $/hr

RCOST = Man-hour related costs in $

CPROF = Contractor's profit percentage

Variable Name	Dimension	Limit	Format
SNAME	-	Max. 30 characters	30A1
HRMAN	hrs	-	F10.0
RATE	$/hr	-	F10.0
RCOST	$	-	F10.0
CPROF	-	0. to 1.0	F10.0

5.1 Propulsion Maintenance Costs

N = Number of propulsion maintenance cost items

MILE = Kilometers traveled during each year for ten years

Variable Name	Dimension	Limit	Format
N	-	-	I6
MILE	km.	-	10I6

5.2 Propulsion Maintenance Cost Item Data

SNAME = Propulsion maintenance cost item name

INTERV = Scheduled maintenance interval in km

TIME = Mean time to repair, replace, and inspect in hrs

RATE = Labor rate in $/hr

PART = Part cost per maintenance interval in $

Variable Name	Dimension	Limit	Format
SNAME	-	Max. 30 characters	30A1
INTERV	km	-	I10
TIME	hr	-	F10.0
RATE	$/hr	-	F10.0
PART	$	-	F10.0

6.1 Operating Costs

KFUEL = Number of different energy sources used in the vehicle

KMAINT = Number of different maintenance and repair items except the propulsion maintenance

KOTHER = Number of other operating costs

Variable Name	Dimension	Limit	Format
KFUEL	-		I5
KMAINT	-	(KFUEL + KMAINT + KOTHER $\leq$ 20)	I5
KOTHER	-		I5

6.2 <u>Energy Source Item Name</u>

OPNAME = Energy Source Name

UNIT1 = Energy price units ($/ℓ)

Variable Name	Dimension	Limit	Format
OPNAME		Max. 25 characters	25A1
UNIT1	e.g., $/kW-hr	Max. 10 characters	10A1

6.3 <u>Energy Source Data</u>

ENERGY = Energy unit price forecasted in 1978 $

UNIT2 = Energy consumption unit (km/ℓ)

ROAD = Energy consumption rate (km/ℓ)

Variable Name	Dimension	Limit	Format
ENERGY	e.g., $/kW-hr	-	10F5.0
UNIT2		Max. 10 characters	10A1
ROAD	e.g.,km/kW-hr	-	F10.0

<u>REPEAT 6.2 and 6.3 KFUEL TIMES</u>

6.4 <u>Maintenance and Repair Cost Data</u>

OPNAME = Maintenance and repair cost item name

ROAD = Maintenance and repair unit cost in $/km

UNIT1 = $/km

Variable Name	Dimension	Limit	Format
OPNAME	-	Max. 25 characters	25A1
ROAD	$/km	-	F10.0
UNIT1	-	Max. 10 characters	10A1

<u>REPEAT 6.4 KMAINT TIMES</u>

6.5 Other Operating Cost Data

OPNAME = Other operating cost item name

ROAD = Other operating cost in $/km

UNIT1 = $/km

Variable Name	Dimension	Limit	Format
OPNAME	-	Max. 25 characters	25A1
ROAD	$/km	-	F10.0
UNIT1	-	Max. 10 characters	10A1

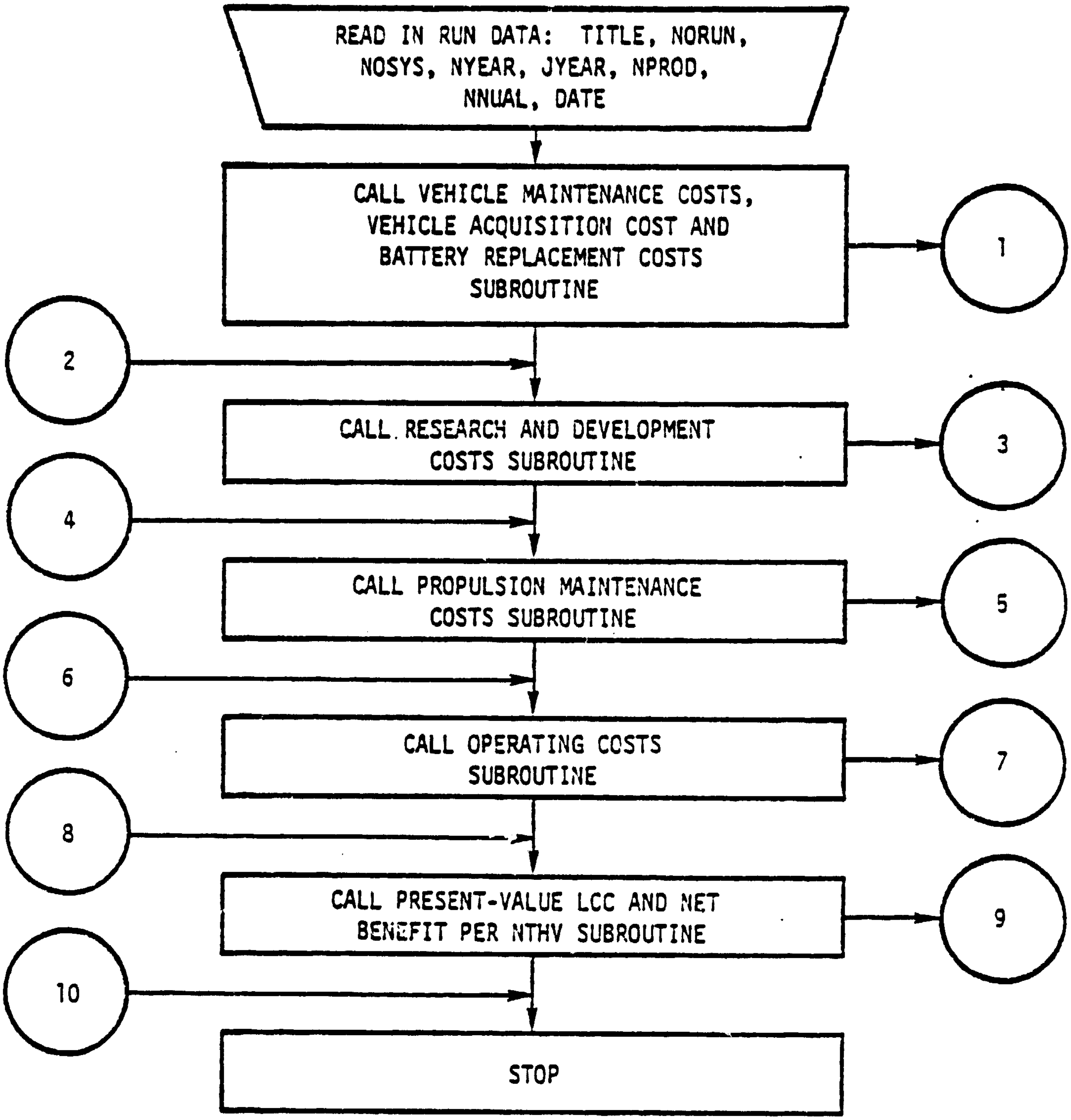
7.1 Life Cycle Cost of a Conventional ICE Vehicle to be Replaced by a NTHV

PCCICE = Life cycle cost per ICE vehicle in 1978 $ discounted at the same rate as the NTHV

PETICE = Petroleum cost per ICE vehicle in 1978 $ discounted at the same rate as the NTHV

Variable Name	Dimension	Limit	Format
PCCICE	$	-	F10.0
PETICE	$	-	F10.0

FLOW CHART OF THE COMPUTER PROGRAM



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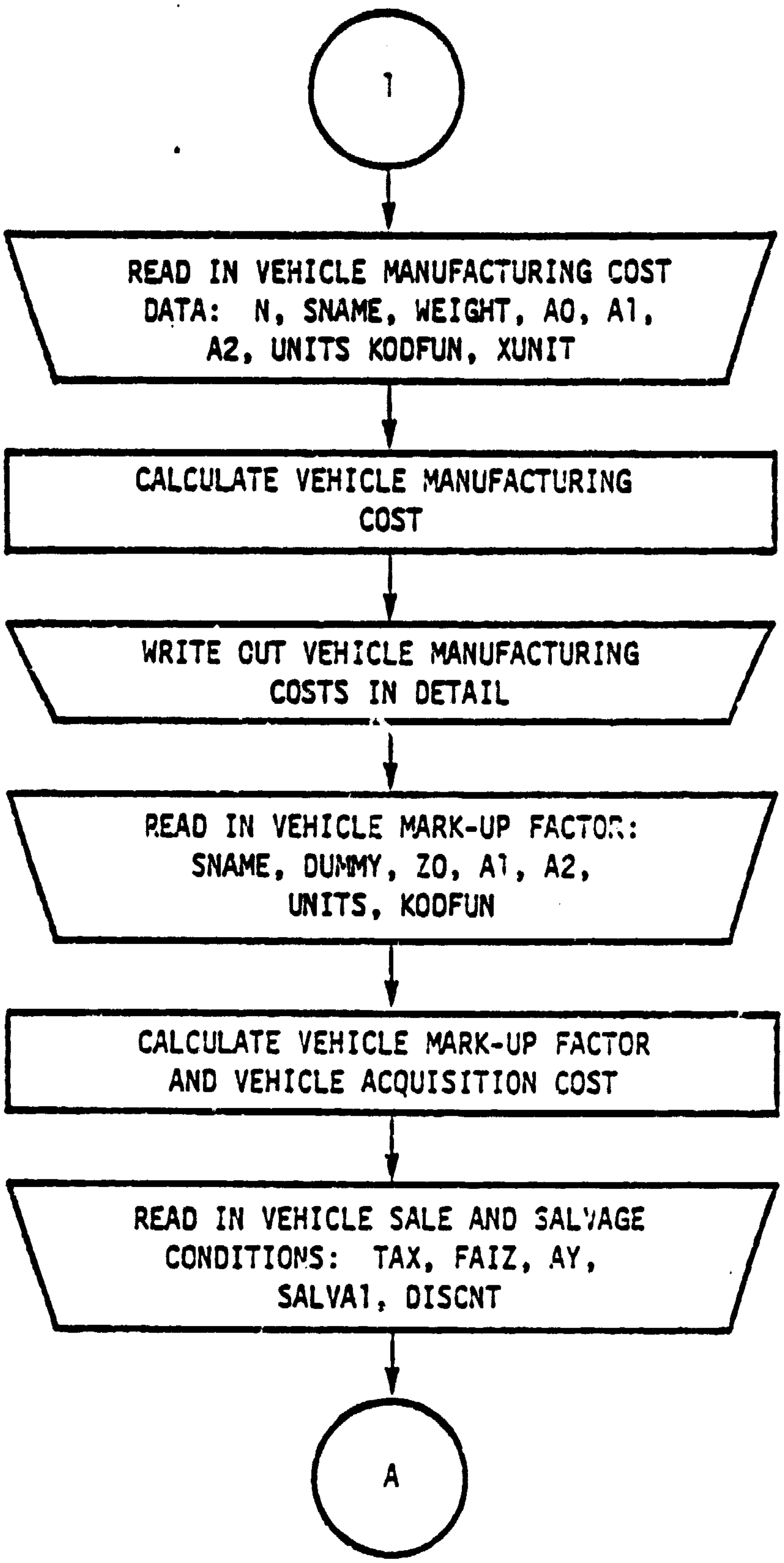
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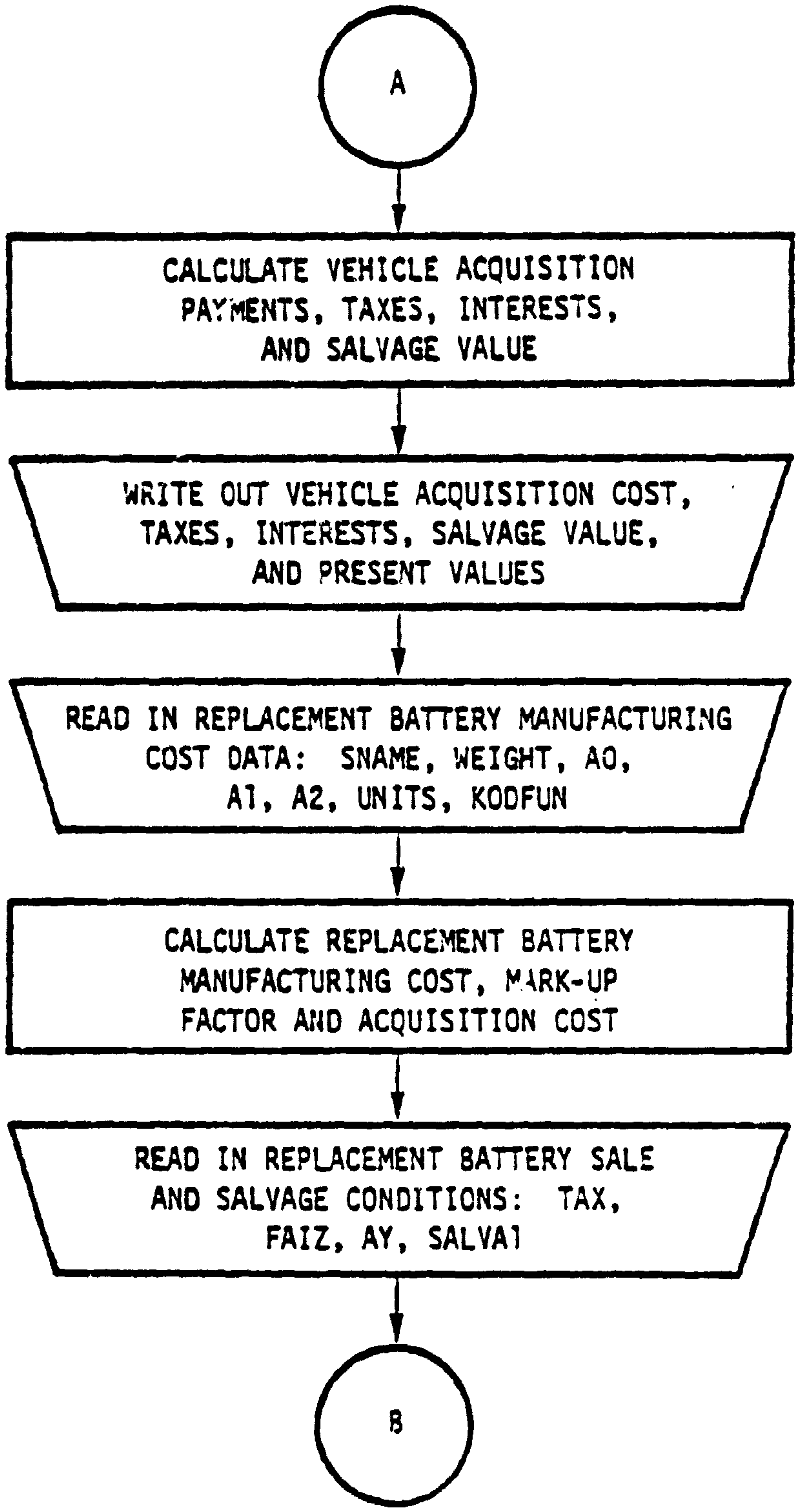
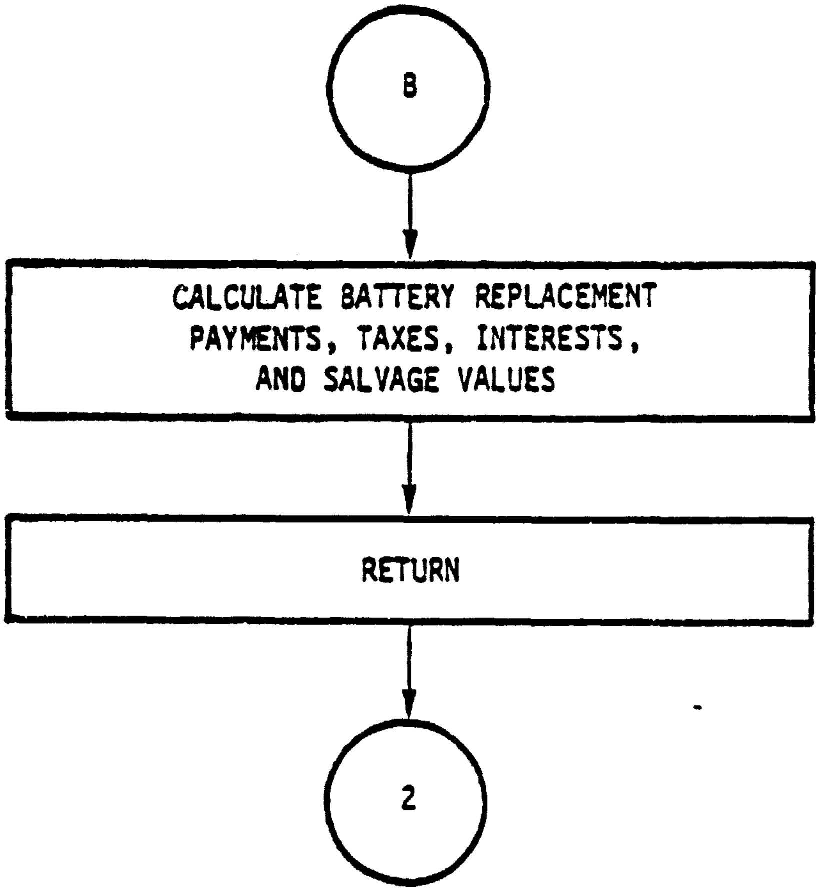
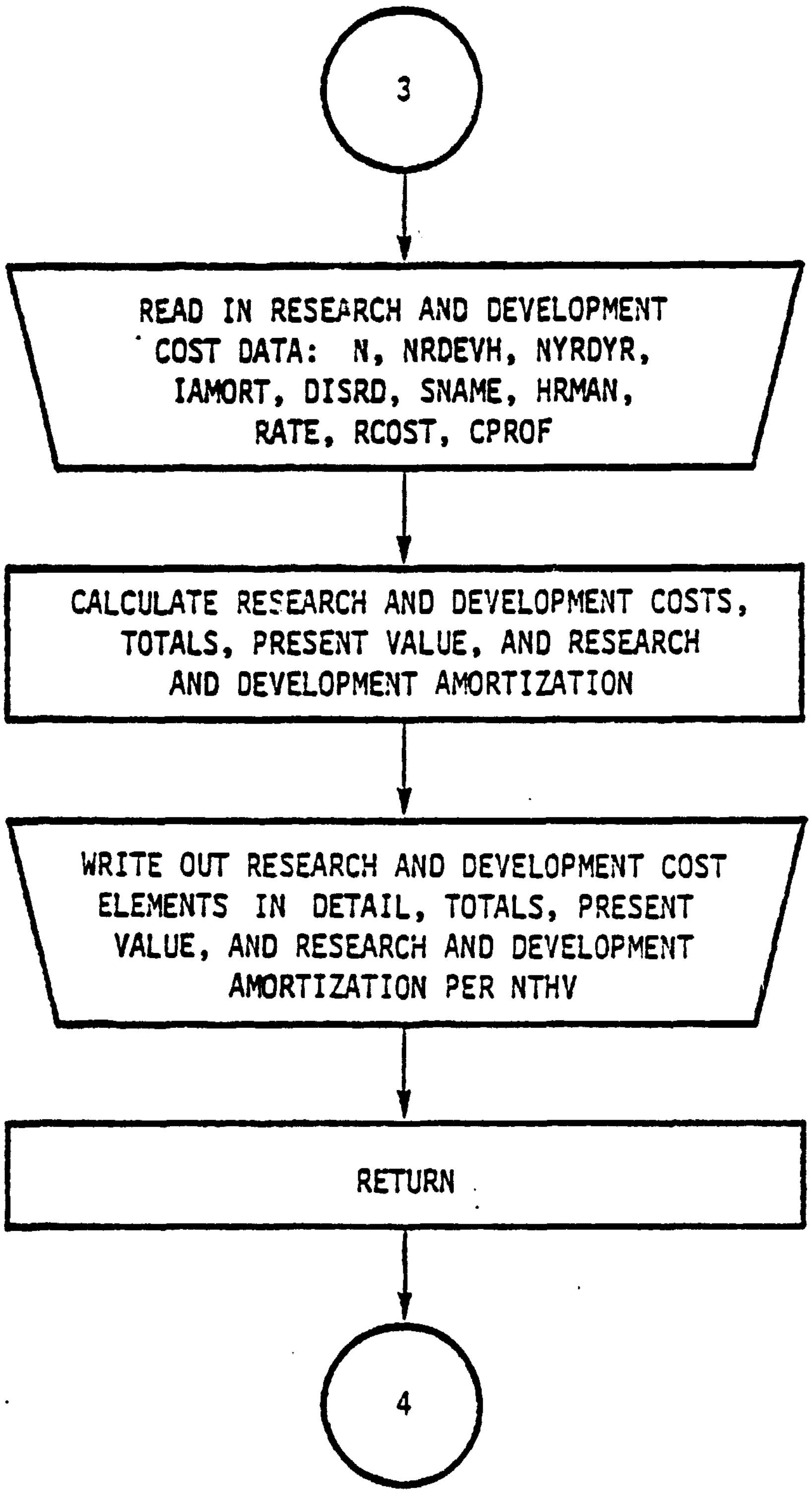
READ IN VEHICLE MANUFACTURING COST DATA: N, SNAME, WEIGHT, A0, A1, A2, UNITS KODFUN, XUNIT
CALCULATE VEHICLE MANUFACTURING COST
WRITE OUT VEHICLE MANUFACTURING COSTS IN DETAIL
READ IN VEHICLE MARK-UP FACTOR: SNAME, DUMMY, Z0, A1, A2, UNITS, KODFUN
CALCULATE VEHICLE MARK-UP FACTOR AND VEHICLE ACQUISITION COST
READ IN VEHICLE SALE AND SALVAGE CONDITIONS: TAX, FAIZ, AY, SALVA1, DISCNT
A


A
CALCULATE VEHICLE ACQUISITION PAYMENTS, TAXES, INTERESTS, AND SALVAGE VALUE
WRITE OUT VEHICLE ACQUISITION COST, TAXES, INTERESTS, SALVAGE VALUE, AND PRESENT VALUES
READ IN REPLACEMENT BATTERY MANUFACTURING COST DATA: SNAME, WEIGHT, A0, A1, A2, UNITS, KODFUN
CALCULATE REPLACEMENT BATTERY MANUFACTURING COST, MARK-UP FACTOR AND ACQUISITION COST
READ IN REPLACEMENT BATTERY SALE AND SALVAGE CONDITIONS: TAX, FAIZ, AY, SALVA1
B


B
CALCULATE BATTERY REPLACEMENT PAYMENTS, TAXES, INTERESTS, AND SALVAGE VALUES
RETURN
2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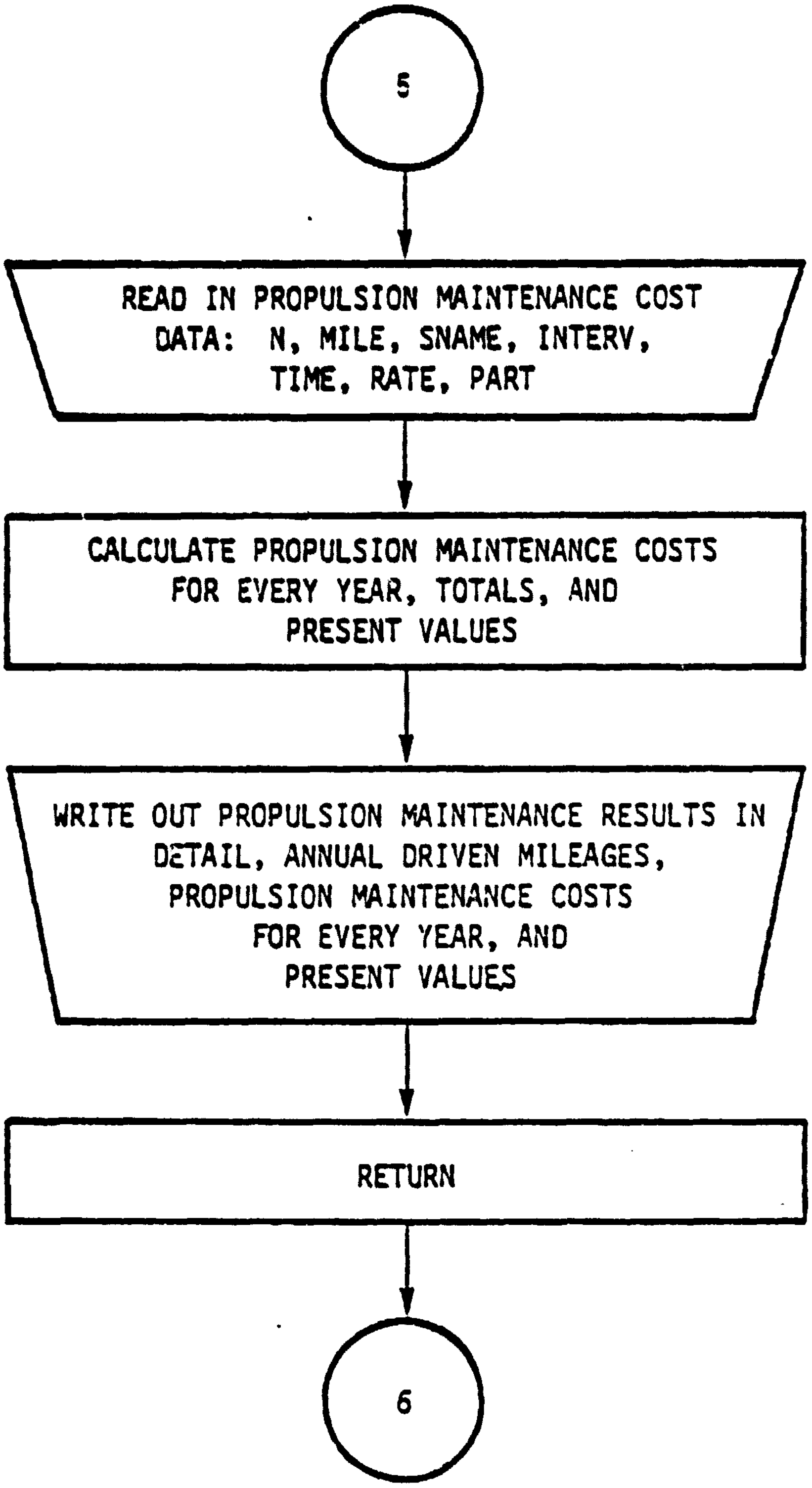
READ IN RESEARCH AND DEVELOPMENT COST DATA: N, NRDEVH, NYRDYR, IAMORT, DISRD, SNAME, HRMAN, RATE, RCOST, CPROF
CALCULATE RESEARCH AND DEVELOPMENT COSTS, TOTALS, PRESENT VALUE, AND RESEARCH AND DEVELOPMENT AMORTIZATION
WRITE OUT RESEARCH AND DEVELOPMENT COST ELEMENTS IN DETAIL, TOTALS, PRESENT VALUE, AND RESEARCH AND DEVELOPMENT AMORTIZATION PER NTHV
RETURN
4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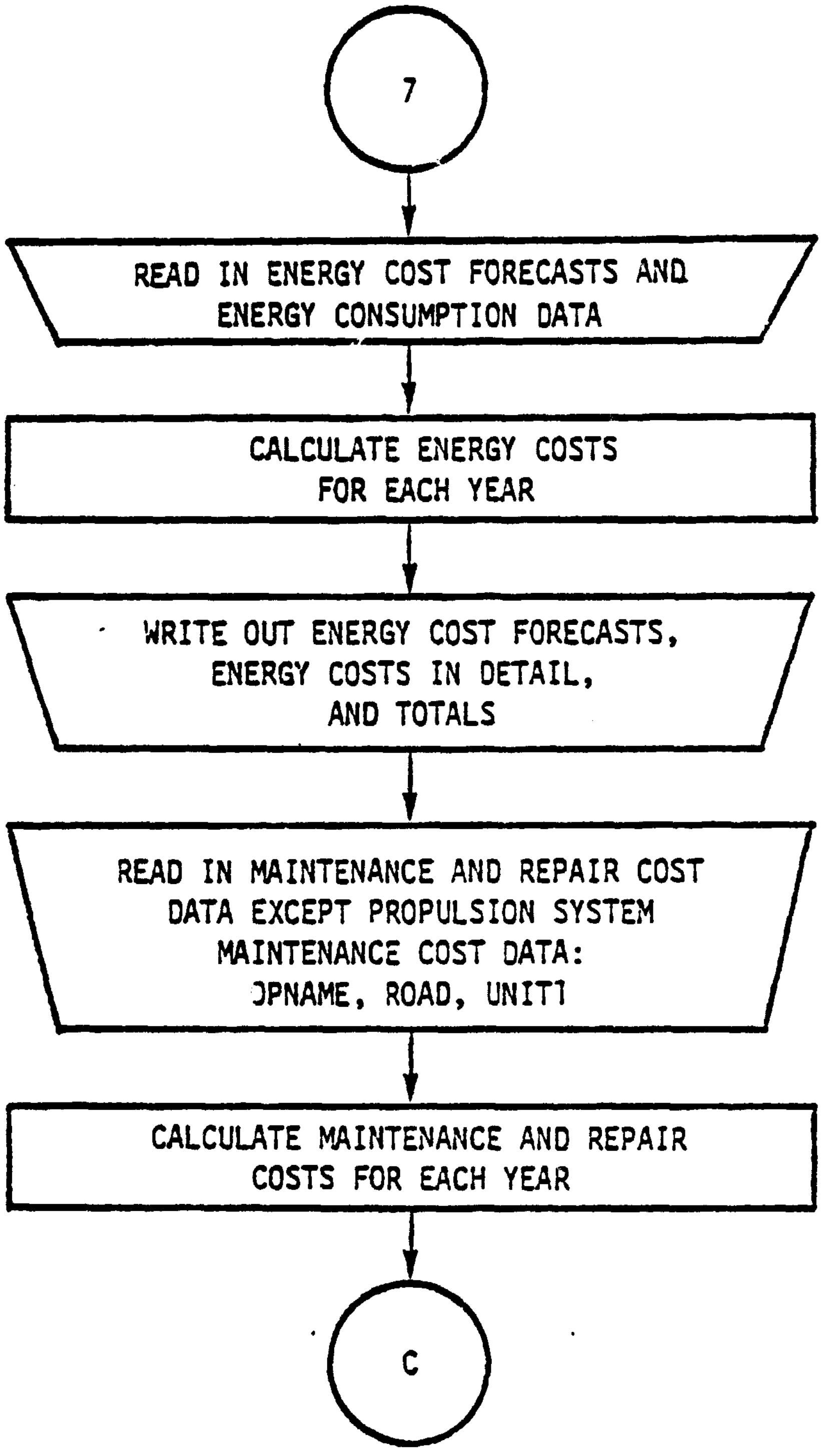
READ IN PROPULSION MAINTENANCE COST DATA: N, MILE, SNAME, INTERV, TIME, RATE, PART
CALCULATE PROPULSION MAINTENANCE COSTS FOR EVERY YEAR, TOTALS, AND PRESENT VALUES
WRITE OUT PROPULSION MAINTENANCE RESULTS IN DETAIL, ANNUAL DRIVEN MILEAGES, PROPULSION MAINTENANCE COSTS FOR EVERY YEAR, AND PRESENT VALUES
RETURN
6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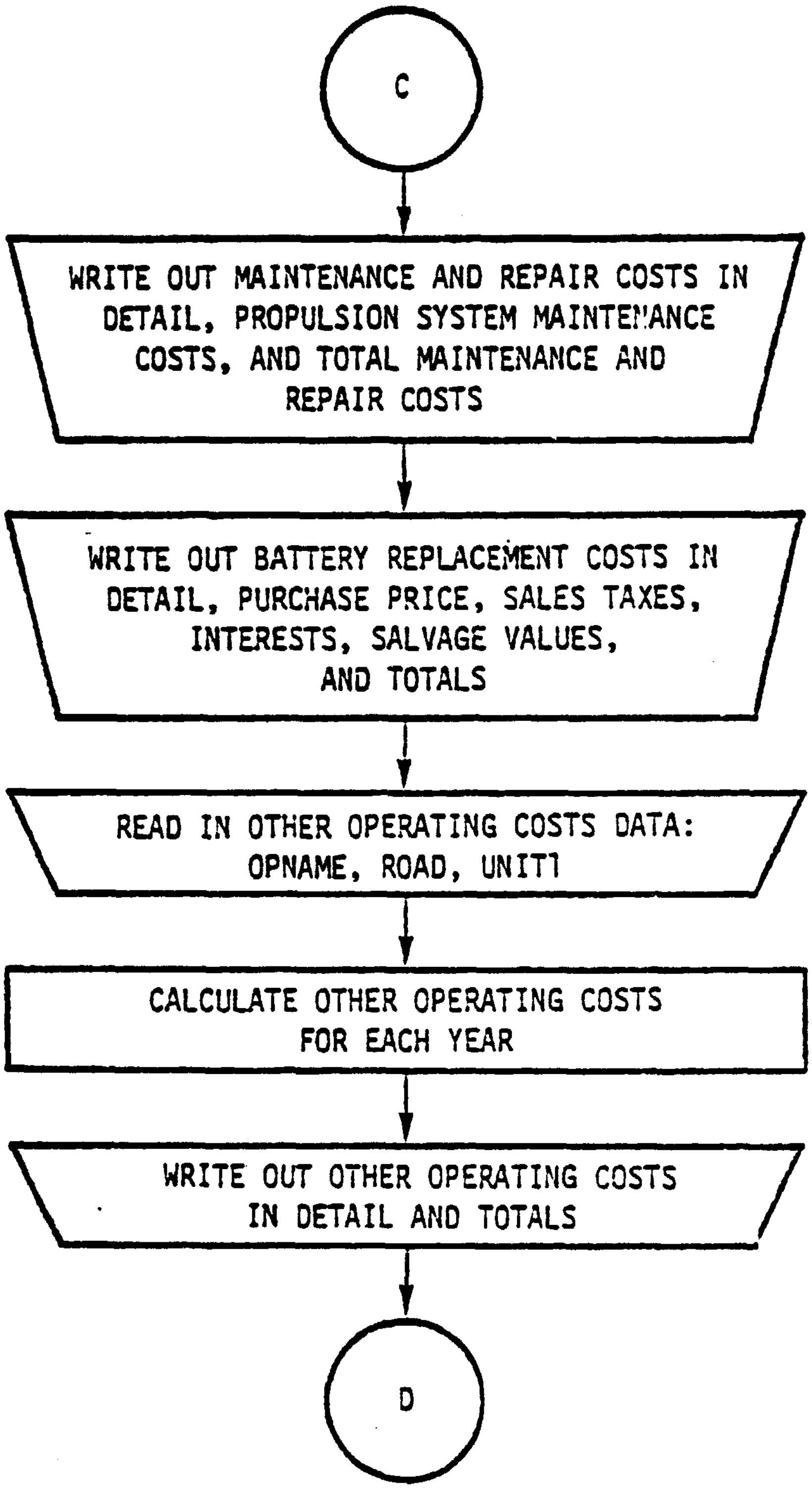
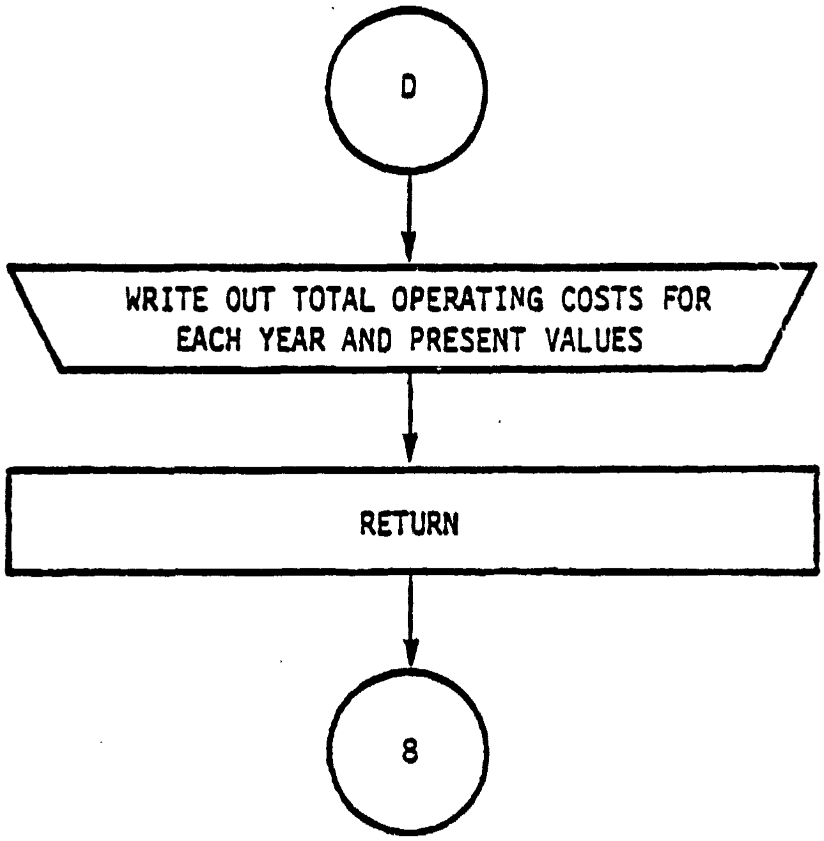
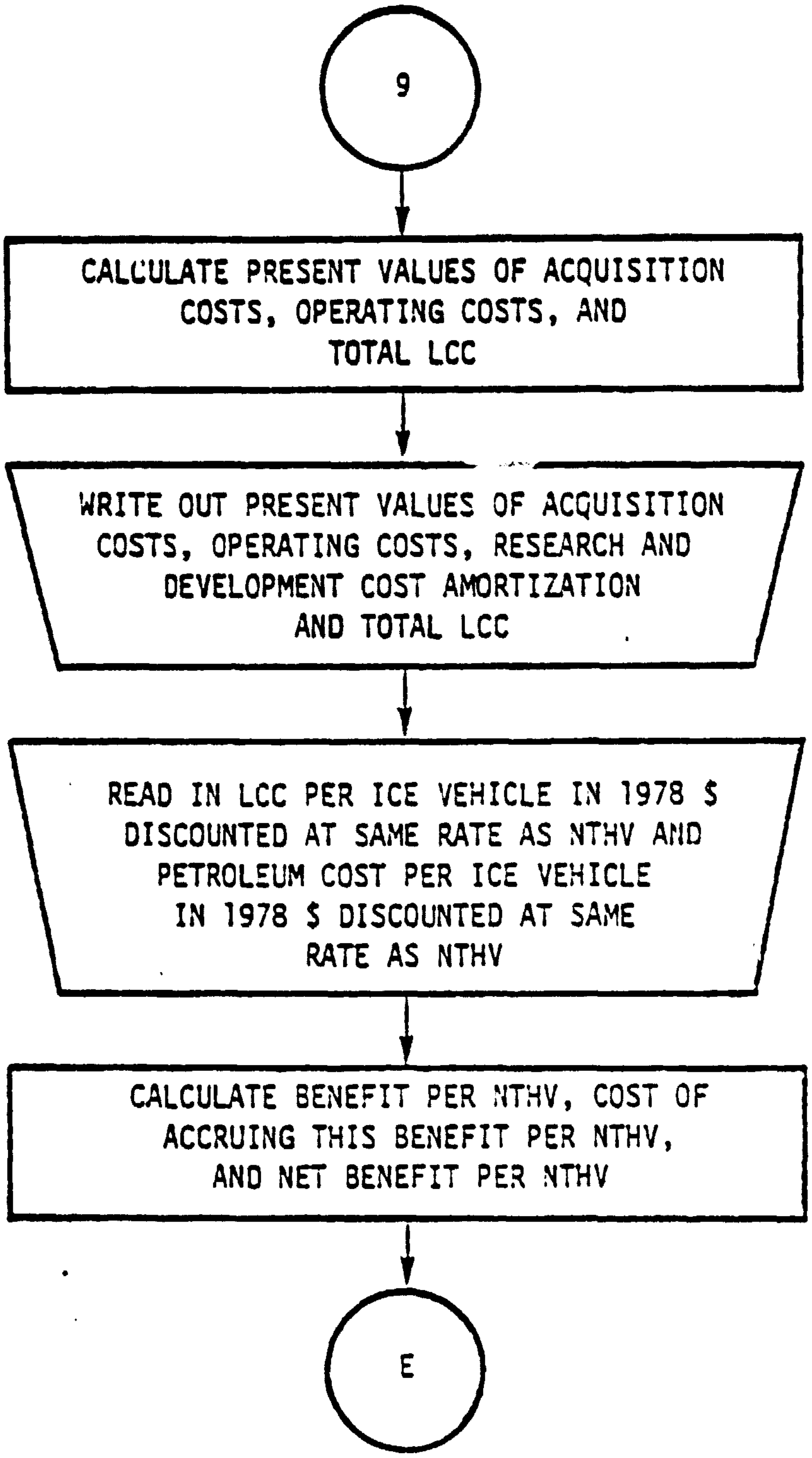
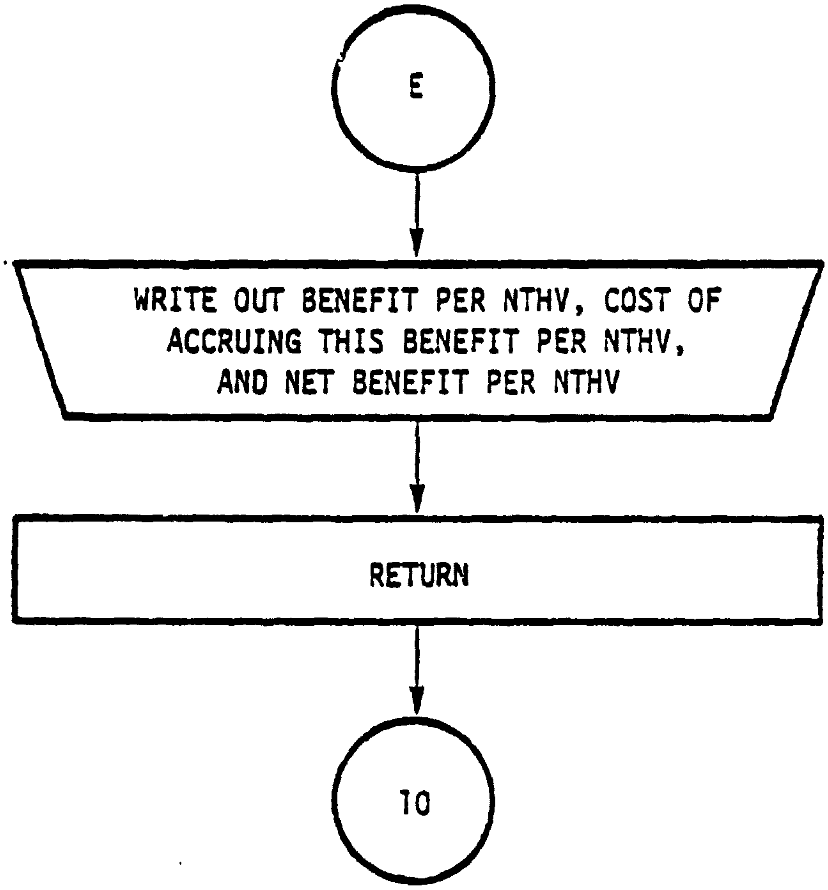
READ IN ENERGY COST FORECASTS AND ENERGY CONSUMPTION DATA
CALCULATE ENERGY COSTS FOR EACH YEAR
WRITE OUT ENERGY COST FORECASTS, ENERGY COSTS IN DETAIL, AND TOTALS
READ IN MAINTENANCE AND REPAIR COST DATA EXCEPT PROPULSION SYSTEM MAINTENANCE COST DATA: OPNAME, ROAD, UNIT1
CALCULATE MAINTENANCE AND REPAIR COSTS FOR EACH YEAR
C


C
WRITE OUT MAINTENANCE AND REPAIR COSTS IN DETAIL, PROPULSION SYSTEM MAINTENANCE COSTS, AND TOTAL MAINTENANCE AND REPAIR COSTS
WRITE OUT BATTERY REPLACEMENT COSTS IN DETAIL, PURCHASE PRICE, SALES TAXES, INTERESTS, SALVAGE VALUES, AND TOTALS
READ IN OTHER OPERATING COSTS DATA: OPNAME, ROAD, UNIT1
CALCULATE OTHER OPERATING COSTS FOR EACH YEAR
WRITE OUT OTHER OPERATING COSTS IN DETAIL AND TOTALS
D


D
WRITE OUT TOTAL OPERATING COSTS FOR EACH YEAR AND PRESENT VALUES
RETURN
8


9
CALCULATE PRESENT VALUES OF ACQUISITION COSTS, OPERATING COSTS, AND TOTAL LCC
WRITE OUT PRESENT VALUES OF ACQUISITION COSTS, OPERATING COSTS, RESEARCH AND DEVELOPMENT COST AMORTIZATION AND TOTAL LCC
READ IN LCC PER ICE VEHICLE IN 1978 $ DISCOUNTED AT SAME RATE AS NTHV AND PETROLEUM COST PER ICE VEHICLE IN 1978 $ DISCOUNTED AT SAME RATE AS NTHV
CALCULATE BENEFIT PER NTHV, COST OF ACCRUING THIS BENEFIT PER NTHV, AND NET BENEFIT PER NTHV
E


E
WRITE OUT BENEFIT PER NTHV, COST OF ACCRUING THIS BENEFIT PER NTHV, AND NET BENEFIT PER NTHV
RETURN
10

THE LISTING OF THE COMPUTER PROGRAM

```
// JOB (3189,GOS4200,,2)
// EXEC FORTXCL
//FORT.SYSIN DD *
C     LIFE CYCLE COST COMPUTER PROGRAM
C     MAIN PROGRAM
      COMMON NIN,NOUT,TITLE(80),NCRUN,NOSYS,NYEAR,JYEAR,NPROD,NNUAL,
     1DATE(20),ACQ(4,11),BACOST(4,11),TAX,FAIZ,AI,SALVA1,RECCST,IAMCRT,
     2MILE(10),PROPUL(11),OPNAME(20,25),OPCOST(20,11),KFUEL,KMAINT,
     3KOTHER,DISCNT,AKU
C     COMPUTER'S INPUT AND OUTPUT SYSTEM CODE NUMBERS
      DO 10 I=1,4
      DO 11 J=1,11
      BACOST(I,J)=0.
   11 ACQ(I,J)=0.
   10 CONTINUE
      DO 12 I=1,10
   12 MILE(I)=0.
      DO 13 I=1,11
   13 PROPUL(I)=0.
      DO 20 I=1,20
      DO 21 J=1,11
   21 OPCOST(I,J)=0.
   20 CONTINUE
      NIN=5
      NOUT=6
      READ(NIN,1) TITLE
    1 FORMAT(80A1)
      READ(NIN,2) NCRUN,NOSYS,NYEAR,JYEAR,NPROD,NNUAL,DATE
    2 FORMAT(6I10,20A1)
      CALL VACOST
      CALL RECOSS
      CALL PROPUN
      CALL OPCOSS
      CALL LCCOST
      STOP
      END
      SUBROUTINE VACOST
      COMMON NIN,NOUT,TITLE(80),NCRUN,NOSYS,NYEAR,JYEAR,NPROD,NNUAL,
     1DATE(20),ACQ(4,11),BACOST(4,11),TAX,FAIZ,AI,SALVA1,RECCST,IAMCRT,
     2MILE(10),PROPUL(11),OPNAME(20,25),OPCOST(20,11),KFUEL,KMAINT,
     3KOTHER,DISCNT,AKU
      DIMENSION SNAME(50,30),WEIGHT(50),A0(50),A1(50),A2(50),
     1UNITS(50,6),KODFUN(50),XUNIT(50),IYEAR(11),B(11),B1(11),BT(120),
     2BTIN(120),BT1(11),BTIN1(11),BTSAL(11),BTAX(11)
      REAL*8 A10
      REAL*8 A11
      REAL*8 A12
      REAL*8 FUNCTN
      DATA A10/'W'/
      DATA A11/'LN(W)'/
      DATA A12/'SIN(W)'/
      SUMW=0.
      SUMC=0.
      DO 701 I=1,11
      IYEAR(I)=0.
      B(I)=0.
      B1(I)=0.
      BT1(I)=0.
      BTIN1(I)=0.
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```
      BTSAL(I)=0.
  701 BTAX(I)=0.
      DO 702 I=1,120
      BT(I)=0.
  702 BTIN(I)=0.
      READ(NIN,1) N
    1 FORMAT(I5)
      DO 2 I=1,N
      READ(NIN,3) (SNAME(I,J),J=1,30),WEIGHT(I),A0(I),A1(I),A2(I),
     1(UNITS(I,J),J=1,6),KODFUN(I),XUNIT(I)
    3 FORMAT(30A1,F5.0,3E11.4,6A1,I1,F5.0)
C     WEIGHT=COMPONENT OR SYSTEM WEIGHT IN KG
C     UNIT COST=A0+A1*W+A2*W*W
C     W=SUM OF 'WEIGHTS',NAMELY CORE WEIGHT OF THE VEHICLE
C     UNITS=UNIT OF THE UNIT COST (I.E. $/KW )
C     KODFUN=FUNCTION CODE (I.E. KODFUN=2 MEANS W=SIN(W) )
C     XUNIT=IF UNIT COST IS DIFFERENT THAN $/KG  SUCH AS $/KW,THEN
C     XUNIT=....KW . IF UNIT COST IS $/KG , THEN XUNIT=).
    2 SUMW=SUMW+WEIGHT(I)
      DO 4 I=1,N
      IF(KODFUN(I).EQ.0) X=SUMW
      IF(KODFUN(I).EQ.1) X=ALOG(SUMW)
      IF(KODFUN(I).EQ.2) X=SIN(SUMW)
      Y=A0(I)+A1(I)*X+A2(I)*X*X
      IF(XUNIT(I).EQ.0) XUNIT(I)=WEIGHT(I)
C     FOR I=N, VEHICLE ASSEMBLY COST
      IF(I.EQ.N) XUNIT(I)=SUMW
C     COST OF COMPONENT IN $
      XUNIT(I)=Y*XUNIT(I)
C     TOTAL MANUFACTURING COST
    4 SUMC=SUMC+XUNIT(I)
C     START OUTPUTTING THE TABLE AND CALCULATE COST/KG .
      WRITE(NOUT,51)
   51 FORMAT(1H1,130('-'))
      WRITE(NOUT,5) TITLE
    5 FORMAT(1H0,26X,80A1)
      WRITE(NOUT,6) NCRUN
    6 FORMAT(1H0,47X,'VEHICLE ACQUISITION COST BREAKDOWN',22X,
     1'RUN NO.',I4)
      WRITE(NOUT,7)NYEAR,DATE
    7 FORMAT(1H0,59X,'(',I5,' $ )',34X,'DATE   ',20A1)
      WRITE(NOUT,8)NNUAL,NSRCD,NCSYS
    8 FORMAT(1H0,37X,'ANNUAL PRODUCTION RATE ',I7,' VEHICLES/YR FOR',
     1I2,' YEARS',12X,'SYSTEM PACKAGE NO.',I4)
      WRITE(NOUT,9)
    9 FORMAT(1H0,59X,'% OF',40X,'W=CORE WEIGHT')
      WRITE(NOUT,10)
   10 FORMAT(1H ,30X,'WEIGHT',4X,'COST',3X,'COST/KG ',4X,'MANUF.')
      WRITE(NOUT,109)
  109 FORMAT(1H ,'MANUFACTURING COSTS',12X,'(KG )',5X,'($)',4X,'($/KG )'
     1,4X,'COSTS',9X,'UNIT COST ESTIMATE RELATIONSHIP',10X,'FUNCTION',
     22X,'UNITS')
      WRITE(NOUT,11)
   11 FORMAT(1H ,19('-'),11X,6('-'),3X,6('-'),3X,7('-'),3X,6('-'),9X,
     131('-'),10X,8('-'),2X,5('-'))
      WRITE(NOUT,108)
  108 FORMAT(1H )
      DO 12 I=1,N
      IF(I.LT.N) RATIO1=XUNIT(I)/WEIGHT(I)
      IF(I.EQ.N) RATIO1=XUNIT(I)/SUMW
```

```
      RATIO2=XUNIT(I)*100./SUMC
      IF(KODFUN(I).EQ.0) FUNCTN=A10
      IF(KODFUN(I).EQ.1) FUNCTN=A11
      IF(KODFUN(I).EQ.2) FUNCTN=A12
      IF(I.LT.N) WRITE(NOUT,13) (SNAME(I,J),J=1,30),WEIGHT(I),XUNIT(I),
     1RATIO1,RATIO2,A0(I),A1(I),A2(I),FUNCTN,(UNITS(I,J),J=1,6)
C     FOR I=N VEHICLE ASSEMBLY COST
   12 IF(I.EQ.N) WRITE(NOUT,14) (SNAME(I,J),J=1,30),XUNIT(I),RATIO1,
     1RATIO2,A0(I),A1(I),A2(I),FUNCTN,(UNITS(I,J),J=1,6)
   13 FORMAT(1H0,30A1,F6.1,2X,F7.2,3X,F7.2,3X,F6.2,2X,'C=' ,E11.4,'+(',
     1E11.4,')*W+(',E11.4,')*W*W',1X,'W=',A6,2X,6A1)
   14 FORMAT(1H0,30A1,8X,F7.2,3X,F7.2,3X,F6.2,2X,'C=',E11.4,'+(',
     1E11.4,')*W+(',E11.4,')*W*W',1X,'W=',A6,2X,6A1)
      WRITE(NOUT,15)
   15 FORMAT(1H ,30X,6('-'),3X,6('-'),13X,6('-'))
      RATIO1=SUMC/SUMW
      RATIO2=100.
      WRITE(NOUT,16)SUMW,SUMC,RATIO1,RATIO2
   16 FORMAT(1H0,'TOTALS',23X,F7.1,1X,F8.2,3X,F7.2,2X,F7.2)
      WRITE(NOUT,161)
  161 FORMAT(1H ,6('-'))
      WRITE(NOUT,17)
   17 FORMAT(1H0)
      WRITE(NOUT,18)
   18 FORMAT(1H ,130('-'))
C     PURCHASE PRICE MARK-UP FACTOR
      READ(NIN,3) (SNAME(N+1,J),J=1,30),DUMMY,A0(N+1),A1(N+1),A2(N+1),
     1(UNITS(N+1,J),J=1,6),KODFUN(N+1)
      DO 19 I=1,11
   19 IYEAR(I)=JYEAR+I-1
      WRITE(NOUT,20) (IYEAR(I),I=1,11)
   20 FORMAT(1H0,33X,11(I5,3X),' TOTAL')
      WRITE(NOUT,21)
   21 FORMAT(1H ,32X,11(7('-'),1X),8('-'))
      IF(KODFUN(N+1).EQ.0)  X=SUMC
      IF(KODFUN(N+1).EQ.1)  X=ALOG(SUMC)
      IF(KODFUN(N+1).EQ.2)  X=SIN(SUMC)
      UPMARK=A0(N+1)+A1(N+1)*X+A2(N+1)*X*X
      PRICE=UPMARK*SUMC
      READ(NIN,22)TAX,FAIR,AY,SALVA1,DISCNT
   22 FORMAT(8F10.0)
      IAY=AY
      IPAY=12
      IF(AY.EQ.0.)B(1)=PRICE
      IF(AY.EQ.0.)GO TO 25
      PAY=PRICE/AY
      N=1
      DO 23 I=1,120
      IF(I.GT.IAY)GO TO 25
      IF(I.LE.IPAY)B(N)=B(N)+PAY
      IF(I.EQ.IPAY) N=N+1
      IF(I.EQ.IPAY)IPAY=IPAY+12
   23 CONTINUE
C     WRITE PURCHASE PRICE
   25 WRITE(NOUT,24) UPMARK,(B(I),I=1,10),PRICE
   24 FORMAT(1H0,'PURCHASE PRICE',' (UF=',F5.2,' )',5X,10F8.2,2X,F9.2)
      WRITE(NOUT,251)
  251 FORMAT(1H ,14('-'))
      DO 252 I=1,10
  252 ACQ(1,I)=B(I)
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C     SALES TAXES
      TAXPAY=TAX*PRICE
      TAX=TAX*100.
      B(1)=B(1)+TAXPAY
      B1(1)=TAXPAY
      WRITE(NOUT,26)TAX,(B1(I),I=1,10),TAXPAY
   26 FORMAT(1H0,'SALES TAXES (',F5.2,' % )',9X,10F8.2,8X,F9.2)
      WRITE(NOUT,27)
   27 FORMAT(1H ,11('-'))
      DO 253 I=1,10
  253 ACQ(2,I)=B1(I)
C     INTEREST CALCULATIONS
      FAIZ1=0.
      B1(1)=0.
      IF(AY.EQ.0.)GO TO 30
      A=AY/12.
      FAIZ1=PRICE*((A*FAIZ/(1.-(1.+FAIZ)**(-A)))-1.)
      FAIZ9=FAIZ1
      PAY=FAIZ1/AY
      IPAY=12
      N=1
      DO 29 I=1,120
      IF(I.GT.IAY)GO TO 30
      IF(I.LE.IPAY) B1(N)=B1(N)+PAY
      IF(I.EQ.IPAY) N=N+1
      IF(I.EQ.IPAY) IPAY=IPAY+12
   29 CONTINUE
   30 FAIZ=FAIZ*100.
      WRITE(NOUT,31) FAIZ,IAY,(B1(I),I=1,10),FAIZ1
   31 FORMAT(1H0,'INTEREST (',F5.2,' % AT',I3,' MOS)',3X,10F8.2,8X,F9.2)
      WRITE(NOUT,32)
   32 FORMAT(1H ,8('-'))
      DO 254 I=1,10
  254 ACQ(3,I)=B1(I)
C     SALVAGE VALUE OF THE VEHICLE
      A=-PRICE*SALVA1
      B(11)=A
      SALVA1=SALVA1*100.
      WRITE(NOUT,33) SALVA1,A,A
   33 FORMAT(1H0,'SALVAGE VALUE OF VEH (',F5.2,' % )',80X,F8.2,F9.2)
      ACQ(4,11)=A
      WRITE(NOUT,34)
   34 FORMAT(1H ,20('-'),12X,11(7('-'),1X),8('-'))
      DO 344 I=1,11
      B(I)=B(I)+B1(I)
  344 B1(I)=0.
C     BATTERY REPLACEMENT COSTS
      READ(NIN,3) (SNAME(1,J),J=1,30),WEIGHT(1),A0(1),A1(1),A2(1),
     1(UNITS(1,J),J=1,6),KODFUN(1)
      IF(KODFUN(1).EQ.0) X=WEIGHT(1)
      IF(KODFUN(1).EQ.1) X=ALOG(WEIGHT(1))
      IF(KODFUN(1).EQ.2) X=SIN(WEIGHT(1))
C     BATTERY OEM COST, $/KG
      Y=A0(1)+A1(1)*X+A2(1)*X*X
      BATOEM=Y*WEIGHT(1)
C     READ IN BATTERY RETAIL MARKUP FACTOR
      READ(NIN,3) (SNAME(2,J),J=1,30),BMARKE,A0(2),A1(2),A2(2),
     1(UNITS(2,J),J=1,6),KODFUN(2)
      READ(NIN,22)TAX,FAIZ,AY,SALVA1
      IF(KODFUN(2).EQ.0) X=BATOEM
```

```
      IF(KCOFUN(2).EQ.1) X=ALOG(SATCIN)
      IF(KCOFUN(2).EQ.2) X=SIN(SATCIN)
      Y=A0(2)+A1(2)*X+A2(2)*X*X
      SPRICE=Y*SATCIN
      AKU=SPRICE
      AY1=(10./SLIFE)-1.
      IA=AY1
      A=IA
      IF(A.LT.AY1) AY1=A+1.
      SATREP=AY1*SPRICE
      IA=12.*SLIFE
      ISUM=IA+1
      DO 90 I=1,119
      IF(I.EQ.ISUM)BT(I)=SPRICE
   90 IF(I.EQ.ISUM)ISUM=ISUM+IA
      DO 350 I=1,10
      DO 351 J=1,12
      I1=(I-1)*12+J
  351 BTSAL(I)=BTSAL(I)+BT(I1)
      BTAX(I)=BTSAL(I)*TAX
  350 BTSAL(I)=-BTSAL(I)*SALVA1
      IF(AY.EQ.0.)AY=1.
      BINS=SPRICE/AY
      IAY=AY
      DO 352 I=1,120
      IF(BT(I).EQ.0.)GO TO 352
      IB=I+1
      IP=I+IAY
      DO 353 J=IB,IP
  353 BTIN(J)=BTIN(J)+BINS
  352 CONTINUE
      DO 354 I=1,10
      DO 355 J=1,12
      I1=(I-1)*12+J
      BT1(I)=BT1(I)+BTIN(I1)
  355 BTIN(I1)=0.
  354 CONTINUE
      FAIZ1=0.
      A=AY/12.
      IF(AY.EQ.1.)GO TO 370
      FAIZ1=SPRICE*((A*FAIZ/(1.-(1.+FAIZ)**(-A)))-1.)
  370 FAY=FAIZ1/AY
      DO 356 I=1,120
      IF(BT(I).EQ.0.)GO TO 356
      IB=I+1
      IP=I+IAY
      DO 357 J=IB,IP
  357 BTIN(J)=BTIN(J)+FAY
  356 CONTINUE
      DO 358 I=1,10
      DO 359 J=1,12
      I1=(I-1)*12+J
  359 BTIN1(I)=BTIN1(I)+BTIN(I1)
  358 CONTINUE
      DO 361 I=1,11
      BACOST(1,I)=BT1(I)
      BACOST(2,I)=BTAX(I)
      BACOST(3,I)=BTIN1(I)
  361 BACOST(4,I)=BTSAL(I)
      IF(AY.EQ.1.)AY=0.
```


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      TOTAL=PRICE+TAXPAY+FAIR9+B(11)
      WRITE(NOUT,41) (B(I),I=1,11),TOTAL
   41 FORMAT(1H0,'TOTALS',25X,11F8.2,F9.2)
      WRITE(NOUT,42)
   42 FORMAT(1H ,6('-'))
C     PRESENT VALUE CALCULATIONS
      TOTAL=0.
      DO 43 I=1,11
      B(I)=B(I)/((1.+DISCNT)**I)
   43 TOTAL=TOTAL+B(I)
      A=DISCNT*100.
      WRITE(NOUT,44) A,(B(I),I=1,11),TOTAL
   44 FORMAT(1H0,'PRESENT VALUE (',F5.2,' % )',7X,11F8.2,F9.2)
      WRITE(NOUT,45)
   45 FORMAT(1H ,13('-'))
      WRITE(NOUT,17)
      WRITE(NOUT,18)
      RETURN
      END
      SUBROUTINE RDCOSS
      COMMON NIN,NOUT,TITLE(80),NCRUN,NCSYS,NYEAR,JYEAR,NPROD,NNUAL,
     1DATE(20),ACQ(4,11),BACOST(4,11),TAX,FAIR,AY,SALVAL,RDCCST,IANCST,
     2BILE(10),PRCFUL(11),CPNAME(20,25),OPCOST(20,11),KFUEL,KMAINT,
     3KOTHER,DISCNT,AKU
      DIMENSION SNAME(30)
      RDCOST=0.
      READ(NIN,5) N,NRDVEH,NRDYR,IANCST,DISRD
    5 FORMAT(4I5,F5.0)
      IF(N.EQ.0) GO TO 151
      WRITE(NOUT,1)
    1 FORMAT(1H1,130('-'))
      WRITE(NOUT,2) TITLE
    2 FORMAT(1H0,26X,80A1)
      WRITE(NOUT,3) NCRUN
    3 FORMAT(1H0,45X,'RESEARCH AND DEVELOPMENT COST SUMMARY',21X,
     1'RUN NO.',I4)
      WRITE(NOUT,4) NYEAR,DATE
    4 FORMAT(1H0,29X,'(',I5,' $ )',34X,'DATE    ',20A1)
      WRITE(NOUT,6) NRDVEH,NCSYS
    6 FORMAT(1H0,52X,'NUMBER OF R+D VEHICLES=',I3,25X,'SYSTEM PACKAGE NO
     1.',I4)
      WRITE(NOUT,7)
    7 FORMAT(1H0,61X,'MAN-HOUR')
      WRITE(NOUT,8)
    8 FORMAT(1H ,30X,'MAN-HOURS',6X,'COMPOSITE',7X,'RELATED',7X,
     1'CONTRACTOR',7X'TOTAL')
      WRITE(NOUT,9)
    9 FORMAT(1H ,'R+D COST ELEMENT',16X,'(HRS)',3X,'RATE($/HR)',
     16X,'COSTS($)',6X,'PROFIT ($)',8X,'COST($)')
      WRITE(NOUT,10)
   10 FORMAT(1H ,16('-'),14X,5(10('-'),5X))
      WRITE(NOUT,11)
   11 FORMAT(1H )
      SUM1=0.
      SUM2=0.
      SUM3=0.
      SUM4=0.
      DO 12 I=1,N
      READ(NIN,13) (SNAME(J),J=1,30),HRMAN,RATE,RCOST,CPROF
   13 FORMAT(30A1,4F10.0)
```

```
      SUM1=SUM1+HRMAN
      SUM2=SUM2+RCOST
      A=HRMAN*RATE+RCOST
      PROF=A*CPROF
      SUM3=SUM3+PROF
      TCOST=A+PROF
      SUM4=SUM4+TCOST
   12 WRITE(NOUT,14) (SNAME(J),J=1,30),HRMAN,RATE,RCOST,PROF,TCOST
   14 FORMAT(1H0,30A1,F10.0,5X,F10.2,3(5X,F10.0))
      WRITE(NOUT,15)
   15 FORMAT(1H ,30X,10('-'),20X,3(10('-'),5X))
      WRITE(NOUT,16) SUM1,SUM2,SUM3,SUM4
   16 FORMAT(1H0,'TOTALS',24X,F10.0,20X,3(F10.0,5X))
      WRITE(NOUT,17)
   17 FORMAT(1H ,6('-'))
      WRITE(NOUT,18)
   18 FORMAT(1H0)
      WRITE(NOUT,19)
   19 FORMAT(1H ,130('-'))
      SUM1=0.
      A=NRDYR
      A=SUM4/A
      DO 20 I=1,NRDYR
      B=A*(1.+DISRD)**I
   20 SUM1=SUM1+B
      DISRD=100.*DISRD
      WRITE(NOUT,21)DISRD,NRDYR,SUM1
   21 FORMAT(1H0,'PRESENT VALUE OF R+D COSTS AT ',F5.2,' % DISCOUNT RATE
     1 AND FOR ',I3,' YEARS OF EQUAL ANNUAL COSTS IS',F15.0,' $')
      A=IAMORT*NNUAL
      RDCOST=SUM1/A
      IAMORT=A
      WRITE(NOUT,22)RDCOST,IAMORT
   22 FORMAT(1H0,'R+D AMORTIZATION PER STRV VEHICLE IS',F7.2,' $ FOR',
     1I8,' VEHICLES')
      WRITE(NOUT,18)
      WRITE(NOUT,19)
  151 CONTINUE
      RETURN
      END
      SUBROUTINE PROPUN
      COMMON NIN,NOUT,TITLE(80),NORUN,NOSYS,NYEAR,JYEAR,NPROD,NNUAL,
     1DATE(20),ACQ(4,11),RACOST(4,11),TAX,RATE,AT,SALVAL,RDCOST,IAMORT,
     2MILE(10),PROPUL(11),OPNAME(20,25),OPCOST(20,11),KFUEL,KURINT,
     3KOTHER,DISCNT,AKU
      DIMENSION C(11),D(11),ICUM(10),SNAME(30)
      DO 701 I=1,11
      C(I)=0.
  701 D(I)=0.
      DO 702 I=1,10
  702 ICUM(I)=0.
      WRITE(NOUT,1)
    1 FORMAT(1H1,130('-'))
      WRITE(NOUT,2)
    2 FORMAT(1H0,26X,80A1)
      WRITE(NOUT,3) NORUN
    3 FORMAT(1H0,46X,'PROPULSION SYSTEM MAINTENANCE COSTS',22X,
     1'RUN NO.',I4)
      WRITE(NOUT,4) NYEAR,DATE
    4 FORMAT(1H0,59X,' (',I5,' $ )',34X,'DATE    ',20A1)
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```
      READ(NIN,5)N,(MILE(I),I=1,10)
    5 FORMAT(11I6)
      WRITE(NOUT,6) NCSYS
    6 FORMAT(1H0,100X,'SYSTEM PACKAGE NO.',I4)
      WRITE(NOUT,7)
    7 FORMAT(1H0,30X,'SCHEDULED MAINT',5X,'MEAN TIME TO REPAIR/',
     125X,'PARTS COST/MAINT',3X,'LIFETIME TOTAL')
      WRITE(NOUT,8)
    8 FORMAT(1H ,'COMPONENT NAME',17X,'INTERVAL (KM)',6X,'REPLACE/INSPEC
     1T(HRS)',5X,'LABOR RATE($/HR)',6X,'INTERVAL ($)',7X,'COST ($)')
      WRITE(NOUT,9)
    9 FORMAT(1H ,14('-'),16X,15('-'),5X,20('-'),5X,16('-'),3X,
     116('-'),3X,14('-'))
      WRITE(NOUT,11)
   11 FORMAT(1H )
      ISCUM=0
      DO 70 I=1,10
      ISCUM=ISCUM+MILE(I)
      IF(I.EQ.1) ICUM(1)=MILE(1)
   70 IF(I.GT.1)ICUM(I)=ICUM(I-1)+MILE(I)
      DO 80 J=1,N
      READ(NIN,81)(SNAME(K),K=1,30),INTERV,TIME,RATE,PART
   81 FORMAT(30A1,I10,3F10.0)
      INT=INTERV
      DO 82 K=1,11
   82 C(K)=0.
      IF(INT.GE.ISCUM) GO TO 110
  100 DO 83 I=1,10
      IF(INT.LE.ICUM(I)) C(I)=C(I)+(TIME*RATE+PART)
      IF(INT.LE.ICUM(I)) GO TO 110
   83 CONTINUE
  110 IF(INT.LT.ISCUM) INT=INT+INTERV
      IF(INT.LT.ISCUM) GO TO 100
      DO 84 I=1,10
   84 C(11)=C(11)+C(I)
      DO 85 I=1,11
   85 D(I)=D(I)+C(I)
   80 WRITE(NOUT,86) (SNAME(K),K=1,30),INTERV,TIME,RATE,PART,C(11)
   86 FORMAT(1H0,30A1,3X,I7,15X,F7.2,17X,F7.2,13X,F7.2,10X,F8.2)
      WRITE(NOUT,18)
   18 FORMAT(1H0)
      WRITE(NOUT,19)
   19 FORMAT(1H ,130('-'))
      DO 50 I=1,10
   50 ICUM(I)=JYEAR+I-1
      WRITE(NOUT,51) (ICUM(I),I=1,10)
   51 FORMAT(1H0,33X,10(I5,3X),'TOTAL')
      WRITE(NOUT,52)
   52 FORMAT(1H ,32X,11(7('-'),1X))
      WRITE(NOUT,191) (MILE(I),I=1,10),ISCUM
  191 FORMAT(1H0,'ANNUAL MILEAGE',17X,11I8)
      WRITE(NOUT,192)
  192 FORMAT(1H ,14('-'))
      WRITE(NOUT,53) (D(I),I=1,11)
   53 FORMAT(1H0,'PROPUL SYS TOTAL MAINT COSTS',3X,11F8.2)
      WRITE(NOUT,54)
   54 FORMAT(1H ,28('-'))
      DO 63 I=1,10
   63 PROPOL(I)=D(I)
      C(11)=0.
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      DO 60 I=1,10
      D(I)=D(I)/((1.+DISCNT)**I)
   60 D(11)=D(11)+D(I)
      A=100.*DISCNT
      WRITE(NOUT,61) A,(D(I),I=1,11)
   61 FORMAT(1H0,'PRESENT VALUE (',F6.2,' % )',6X,11F8.2)
      WRITE(NOUT,62)
   62 FORMAT(1H ,13('-'))
      WRITE(NOUT,18)
      WRITE(NOUT,19)
      RETURN
      END
      SUBROUTINE OPCOST
      COMMON NIN,NOUT,TITLE(80),NORUN,NOSYS,NYEAR,JYEAR,NSPCD,NNUAL,
     1DATE(20),ACC(4,11),BACCST(4,11),TAX,FAIZ,AT,SALVAL,RDCOST,IAMORT,
     2MILE(10),PROPUL(11),OPNAME(20,25),CPCOST(20,11),KFUEL,KMAINT,
     3KOTHER,DISCNT,ANU
      DIMENSION IKEM(10),UNIT1(20,10),ENERGY(20,10),UNIT2(20,10),
     1ROAD(20),D(11),SUMP(11),SUMT(11)
      DO 701 I=1,11
      D(I)=0.
      SUMP(I)=0.
  701 SUMT(I)=0.
      WRITE(NOUT,1)
    1 FORMAT(1H1,130('-'))
      WRITE(NOUT,2) TITLE
    2 FORMAT(1H0,26X,80A1)
      WRITE(NOUT,3) NORUN
    3 FORMAT(1H0,53X,'TOTAL OPERATING COSTS',29X,'RUN NO.',I4)
      WRITE(NOUT,4) NYEAR,DATE
    4 FORMAT(1H0,59X,'(',I5,' $ )',34X,'DATE     ',20A1)
      WRITE(NOUT,5)    NOSYS
    5 FORMAT(1H0,103X,'SYSTEM PACKAGE NO.',I4)
      DO 6 I=1,10
    6 IKEM(I)=JYEAR+I-1
      WRITE(NOUT,7) (IKEM(I),I=1,10)
    7 FORMAT(1H0,30X,'UNIT COST',12X,10(I5,2X),1X,'TOTAL')
      WRITE(NOUT,8)
    8 FORMAT(1H ,30X,9('-'),11X,10(1X,6('-')),1X,7('-'))
      WRITE(NOUT,9)
    9 FORMAT(1H )
      READ(NIN,99) KFUEL,KMAINT,KOTHER
   99 FORMAT(3I5)
      INMILE=0
      DO 98 I=1,10
   98 INMILE=INMILE+MILE(I)
      WRITE(NOUT,12) (MILE(I),I=1,10),INMILE
   12 FORMAT(1H0,'ANNUAL MILEAGE',26X,'KM',9X,10(I6,1X),I7)
      DO 10 I=1,KFUEL
      READ(NIN,11) (OPNAME(I,J),J=1,25),(UNIT1(I,J),J=1,10)
      READ(NIN,13) (ENERGY(I,J),J=1,10),(UNIT2(I,J),J=1,10),ROAD(I)
   11 FORMAT(25A1,10A1)
   13 FORMAT(10F5.0,10A1,F10.0)
   10 WRITE(NOUT,14) (OPNAME(I,J),J=1,25),(UNIT1(I,J),J=1,10),
     1(ENERGY(I,J),J=1,10)
   14 FORMAT(1H0,25A1,15X,10A1,10F7.3)
      WRITE(NOUT,15)
   15 FORMAT(1H0,'OPERATING COSTS')
      WRITE(NOUT,16)
   16 FORMAT(1H ,15('-'))
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      WRITE(NOUT,9)
      WRITE(NOUT,17)
   17 FORMAT(1H0,'ENERGY')
C     KFUEL=1 SHOULD BE THE PETROLEUM DATA
      DO 18 I=1,KFUEL
      D(11)=0.
      DO 19 J=1,10
      A=ENERGY(I,J)/ROAD(I)
      B=MILE(J)
      D(J)=A*B
      OPCOST(I,J)=D(J)
   19 D(11)=D(11)+D(J)
      DO 920 J=1,11
      SUMP(J)=SUMP(J)+D(J)
  920 SUMT(J)=SUMT(J)+D(J)
   18 WRITE(NOUT,20) (OPNAME(I,J),J=1,25),ROAD(I),(UNIT2(I,J),J=1,10),
     1(D(J),J=1,11)
   20 FORMAT(1H0,5X,25A1,F9.5,1X,10A1,10F7.1,F8.1)
      WRITE(NOUT,21) (SUMP(J),J=1,11)
   21 FORMAT(1H0,10X,'TOTAL ENERGY COSTS',22X,10F7.1,F8.1)
      WRITE(NOUT,9)
      WRITE(NOUT,22)
   22 FORMAT(1H0,'MAINTENANCE AND REPAIR')
      SS=0.
      DO 23 I=1,11
      SUMP(I)=0.
      SUMP(I)=SUMP(I)+PROPUL(I)
      SS=SS+PROPUL(I)
   23 SUMT(I)=SUMT(I)+PROPUL(I)
      WRITE(NOUT,24) (PROPUL(I),I=1,10),SS
   24 FORMAT(1H0,5X,'PROPULSION SYSTEM MAINT',6X,'-',15X,10F7.1,F8.1)
      DO 25 I=1,KMAINT
      I1=KFUEL+I
      READ(NIN,26) (OPNAME(I1,J),J=1,25),ROAD(I),(UNIT1(I,J),J=1,10)
   26 FORMAT(25A1,F10.0,10A1)
      D(11)=0.
      DO 27 J=1,10
      A=MILE(J)
      D(J)=ROAD(I)*A
      OPCOST(I1,J)=D(J)
   27 D(11)=D(11)+D(J)
      DO 28 J=1,11
      SUMT(J)=SUMT(J)+D(J)
   28 SUMP(J)=SUMP(J)+D(J)
   25 WRITE(NOUT,20) (OPNAME(I1,J),J=1,25),ROAD(I),(UNIT1(I,J),J=1,10),
     1(D(J),J=1,11)
      SUMP(11)=SUMP(11)+SS
      WRITE(NOUT,29) (SUMP(J),J=1,11)
   29 FORMAT(1H0,10X,'TOTAL M+R COSTS',25X,10F7.1,F8.1)
      WRITE(NOUT,9)
      WRITE(NOUT,30)
   30 FORMAT(1H0,'BATTERY REPLACEMENT')
      SS=0.
      DO 711 I=1,10
  711 SS=SS+BACOST(1,I)
      WRITE(NOUT,31) AKU,(BACOST(1,I),I=1,10),SS
   31 FORMAT(1H0,5X,'PURCHASE PRICE(',F6.1,' $)',21X,10F7.1,F8.1)
      SS=0.
      DO 712 I=1,10
  712 SS=SS+BACOST(2,I)
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      TAX=TAX*100.
      WRITE(NOUT,33)TAX,(BACCST(2,I),I=1,10),SS
   33 FORMAT(1H0,5X,'SALES TAXES (',F5.2,' % )',23X,10F7.1,F8.1)
      SS=0.
      DO 713 I=1,10
  713 SS=SS+BACOST(3,I)
      FAIZ=100.*FAIZ
      IAY=AY
      WRITE(NOUT,32)FAIZ,IAY,(BACCST(3,I),I=1,10),SS
   32 FORMAT(1H0,5X,'INTEREST(',F5.2,'% AT',I3,' DCS)',19X,10F7.1,F8.1)
      SS=0.
      DO 714 I=1,10
  714 SS=SS+BACOST(4,I)
      SALVA1=100.*SALVA1
      WRITE(NOUT,34)SALVA1,(BACOST(4,I),I=1,10),SS
   34 FORMAT(1H0,5X,'SALVAGE VALUE (',F5.2,' % )',21X,10F7.1,F8.1)
      DO 35 J=1,11
      SUMP(J)=0.
      DO 335 K=1,4
      SUMP(J)=SUMP(J)+BACOST(K,J)
  335 SUMT(J)=SUMT(J)+BACCST(K,J)
   35 CONTINUE
      SS=0.
      DO 727 I=1,10
  727 SS=SS+SUMP(I)
      WRITE(NOUT,36) (SUMP(J),J=1,10),SS
   36 FORMAT(1H0,10X,'TOTAL BAT REPL COSTS',20X,10F7.1,F8.1)
      WRITE(NOUT,5)
      DO 41 J=1,11
   41 SUMP(J)=0.
      WRITE(NOUT,37)
   37 FORMAT(1H0,'OTHER OPERATING COSTS')
      DO 38 I=1,KOTHER
      I1=KFUEL+KMAINT+I
      READ(NIN,26) (OPNAME(I1,J),J=1,25),ROAD(I),(UNIT1(I,J),J=1,10)
      D(11)=0.
      DO 39 J=1,10
      A=MILE(J)
      D(J)=ROAD(I)*A
      OPCOST(I1,J)=D(J)
   39 D(11)=D(11)+D(J)
      DO 40 J=1,11
      SUMP(J)=SUMP(J)+D(J)
   40 SUMT(J)=SUMT(J)+D(J)
   38 WRITE(NOUT,20) (OPNAME(I1,J),J=1,25),ROAD(I),(UNIT1(I,J),J=1,10),
     1(D(J),J=1,11)
      WRITE(NOUT,338) (SUMP(J),J=1,11)
      WRITE(NOUT,42)
  338 FORMAT(1H0,10X,'TOTAL OTHER OP COSTS',20X,10F7.1,F8.1)
   42 FORMAT(1H ,50X,10(1X,6('-')),1X,7('-'))
      WRITE(NOUT,43) (SUMT(I),I=1,11)
   43 FORMAT(1H0,'TOTAL OPERATING COSTS',29X,10F7.1,F8.1)
      WRITE(NOUT,44)
   44 FORMAT(1H ,21('-'))
C     PRESENT VALUE CALCULATIONS
      DO 45 I=1,11
   45 SUMT(I)=SUMT(I)/((1.+DISCNT)**I)
      A=DISCNT*100.
      WRITE(NOUT,46)A,(SUMT(I),I=1,11)
   46 FORMAT(1H0,'PRESENT VALUE ('F5.2,' % )',26X,10F7.1,F8.1)
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      WRITE(NOUT,47)
   47 FORMAT(1H ,13('-'))
      WRITE(NOUT,48)
   48 FORMAT(1H0)
      WRITE(NOUT,49)
   49 FORMAT(1H ,130('-'))
      RETURN
      END
      SUBROUTINE LCCOST
      COMMON NIN,NOUT,TITLE(80),NORUN,NCSYS,NYEAR,JYEAR,NPROD,NNCAL,
     1DATE(20),ACQ(4,11),BACOST(4,11),TAX,RATE,AT,SALVAT,RDCOST,IAMOST,
     2MILE(10),PROPUL(11),OPNAME(20,25),OPCOST(20,11),KFUEL,KMAINT,
     3KOTHER,DISCNT,AKU
      DIMENSION IKEM(11),SUMLCC(11),SUMP(11)
      DO 701 I=1,11
      SUMLCC(I)=0.
  701 SUMP(I)=0.
      WRITE(NOUT,1)
    1 FORMAT(1H1,130('-'))
      WRITE(NOUT,2)TITLE
    2 FORMAT(1H0,26X,80A1)
      WRITE(NOUT,3)NORUN
    3 FORMAT(1H0,44X,'PRESENT VALUE OF TOTAL LIFE CYCLE COSTS',20X,
     1'RUN NO.',I4)
      WRITE(NOUT,4)NYEAR,DATE
    4 FORMAT(1H0,59X,'(',I5,' $ )',34X,'DATE    ',20A1)
      A=DISCNT*100.
      WRITE(NOUT,5)A,NCSYS
    5 FORMAT(1H0,54X,'DISCOUNT RATE=',F5.2,' %',28X,'SYSTEM PACKAGE NO.'
     1,I4)
      DO 6 I=1,11
    6 IKEM(I)=JYEAR+I-1
      WRITE(NOUT,7)(IKEM(I),I=1,11)
    7 FORMAT(1H0,31X,'$/KM',2X,11(I5,2X),1X,'TOTAL',1X,'% OF LCC')
      WRITE(NOUT,8)
    8 FORMAT(1H ,30X,12(6('-'),1X),7('-'),1X,8('-'))
      TMILE=0.
      DO 9 I=1,10
      A=MILE(I)
    9 TMILE=TMILE+A
      M1=KFUEL+KMAINT+KOTHER
      DO 10 I=1,4
      DO 11 J=1,11
      BACOST(I,J)=BACOST(I,J)/((1.+DISCNT)**J)
   11 ACQ(I,J)=ACQ(I,J)/((1.+DISCNT)**J)
   10 CONTINUE
      DO 12 J=1,11
   12 PROPUL(J)=PROPUL(J)/((1.+DISCNT)**J)
      DO 13 I=1,M1
      DO 14 J=1,11
   14 OPCOST(I,J)=OPCOST(I,J)/((1.+DISCNT)**J)
   13 CONTINUE
      SUMLCC(1)=RDCOST
      DO 15 I=1,4
      DO 16 J=1,11
   16 SUMLCC(J)=SUMLCC(J)+(BACOST(I,J)+ACQ(I,J))
   15 CONTINUE
      DO 17 I=1,M1
      DO 18 J=1,11
   18 SUMLCC(J)=SUMLCC(J)+OPCOST(I,J)
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17 CONTINUE
   DO 19 I=1,11
19 SUMLCC(I)=SUMLCC(I)+PROPUL(I)
   PCNTHV=0.
   DO 20 I=1,11
20 PCNTHV=PCNTHV+SUMLCC(I)
   WRITE(NOUT,21)
21 FORMAT(1H )
   WRITE(NOUT,22)
22 FORMAT(1H0,'ACQUISITION COSTS')
   SS=0.
   DO 24 I=1,11
24 SS=SS+ACQ(1,I)
   SPER=SS/TMILE
   PERC=SS*100./PCNTHV
   WRITE(NOUT,23) SPER,(ACQ(1,I),I=1,11),SS,PERC
23 FORMAT(1H0,4X,'PURCHASE PRICE',11X,F7.5,11F7.1,F8.1,2X,F6.2)
   SS=0.
   DO 25 I=1,11
25 SS=SS+ACQ(2,I)
   SPER=SS/TMILE
   PERC=SS*100./PCNTHV
   WRITE(NOUT,26)SPER,(ACQ(2,I),I=1,11),SS,PERC
26 FORMAT(1H0,4X,'SALES TAXES',14X,F7.5,11F7.1,F8.1,2X,F6.2)
   SS=0.
   DO 27 I=1,11
27 SS=SS+ACQ(3,I)
   SPER=SS/TMILE
   PERC=SS*100./PCNTHV
   WRITE(NOUT,28)SPER,(ACQ(3,I),I=1,11),SS,PERC
28 FORMAT(1H0,4X,'INTEREST',17X,F7.5,11F7.1,F8.1,2X,F6.2)
   SS=0.
   DO 29 I=1,11
29 SS=SS+ACQ(4,I)
   SPER=ABS(SS/TMILE)
   PERC=ABS(SS*100./PCNTHV)
   WRITE(NOUT,30) SPER,(ACQ(4,I),I=1,11),SS,PERC
30 FORMAT(1H0,4X,'SALVAGE VALUE OF VEHICLE',1X,F7.5,11F7.1,F8.1,2X,
  1F6.2)
   DO 31 I=1,4
   DO 32 J=1,11
32 SUMP(J)=SUMP(J)+ACQ(I,J)
31 CONTINUE
   SS=0.
   DO 33 I=1,11
33 SS=SS+SUMP(I)
   SPER=SS/TMILE
   PERC=SS*100./PCNTHV
   WRITE(NOUT,34)SPER,(SUMP(I),I=1,11),SS,PERC
34 FORMAT(1H0,'TOTAL ACQUISITION COST',7X,F7.5,11F7.1,F8.1,2X,F6.2)
   WRITE(NOUT,21)
   WRITE(NOUT,38)
38 FORMAT(1H0,'OPERATING COSTS')
   WRITE(NOUT,39)
39 FORMAT(1H0,2X,'ENERGY COSTS')
   DO 40 I=1,KFUEL
   SS=0.
   DO 41 J=1,11
   SUMP(J)=0.
41 SS=SS+OPCOST(I,J)
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      SPER=SS/TMILE
      PERC=SS*100./PCNTHV
      IF(I.EQ.1)PNTHV=SS
   40 WRITE(NOUT,42)(OPNAME(I,J),J=1,25),SPER,(OPCOST(I,J),J=1,11),
     1SS,PERC
   42 FORMAT(1H0,4X,25A1,F7.5,11F7.1,F8.1,2X,F6.2)
      DO 43 I=1,KFUEL
      DO 44 J=1,11
   44 SUMP(J)=SUMP(J)+OPCOST(I,J)
   43 CONTINUE
      SS=0.
      DO 45 I=1,11
   45 SS=SS+SUMP(I)
      SPER=SS/TMILE
      PERC=SS*100./PCNTHV
      WRITE(NOUT,46)SPER,(SUMP(I),I=1,11),SS,PERC
   46 FORMAT(1H0,2X,'TOTAL ENERGY COST',10X,F7.5,11F7.1,F8.1,2X,F6.2)
      WRITE(NOUT,21)
      N=KFUEL+1
      N1=KFUEL+KMAINT
      WRITE(NOUT,35)
   35 FORMAT(1H0,2X,'MAINTENANCE + REPAIR COSTS')
      SS=0.
      DO 36 I=1,11
      SUMP(I)=PROPUL(I)
   36 SS=SS+PROPUL(I)
      SPER=SS/TMILE
      PERC=SS*100./PCNTHV
      WRITE(NOUT,37)SPER,(PROPUL(I),I=1,11),SS,PERC
   37 FORMAT(1H0,4X,'PROPULSION SYSTEM MAINT',2X,F7.5,11F7.1,F8.1,2X,
     1F6.2)
      DO 50 I=N,N1
      SS=0.
      DO 51 J=1,11
   51 SS=SS+OPCOST(I,J)
      SPER=SS/TMILE
      PERC=SS*100./PCNTHV
   50 WRITE(NOUT,42)(OPNAME(I,J),J=1,25),SPER,(OPCOST(I,J),J=1,11),SS,
     1PERC
      DO 53 I=N,N1
      DO 54 J=1,11
   54 SUMP(J)=SUMP(J)+OPCOST(I,J)
   53 CONTINUE
      SS=0.
      DO 55 I=1,11
   55 SS=SS+SUMP(I)
      SPER=SS/TMILE
      PERC=SS*100./PCNTHV
      WRITE(NOUT,56)SPER,(SUMP(I),I=1,11),SS,PERC
   56 FORMAT(1H0,2X,'TOTAL MAINT + REPAIR COST',2X,F7.5,11F7.1,F8.1,
     12X,F6.2)
      WRITE(NOUT,21)
      WRITE(NOUT,57)
   57 FORMAT(1H0,2X,'BATTERY REPLACEMENT COSTS')
      SS=0.
      DO 60 I=1,11
      SUMP(I)=0.
   60 SS=SS+BACOST(1,I)
      SPER=SS/TMILE
      PERC=SS*100./PCNTHV
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      WRITE(NOUT,61)SPER,(BACOST(1,I),I=1,11),SS,PERC
   61 FORMAT(1H0,4X,'BATTERY PURCHASE PRICE',3X,F7.5,11F7.1,F8.1,2X,F6.2
     1)
      SS=0.
      DO 63 I=1,11
   63 SS=SS+BACOST(2,I)
      SPER=SS/TMILE
      PERC=SS*100./PCNTEV
      WRITE(NOUT,64)SPER,(BACOST(2,I),I=1,11),SS,PERC
   64 FORMAT(1H0,4X,'SALES TAXES',14X,F7.5,11F7.1,F8.1,2X,F6.2)
      SS=0.
      DO 62 I=1,11
   62 SS=SS+BACOST(3,I)
      SPER=SS/TMILE
      PERC=SS*100./PCNTEV
      WRITE(NOUT,663)SPER,(BACOST(3,I),I=1,11),SS,PERC
      SS=0.
      DO 65 I=1,11
   65 SS=SS+BACOST(4,I)
      SPER=ABS(SS/TMILE)
      PERC=ABS(SS*100./PCNTEV)
      WRITE(NOUT,66)SPER,(BACOST(4,I),I=1,11),SS,PERC
   66 FORMAT(1H0,4X,'SALVAGE VALUE',12X,F7.5,11F7.1,F8.1,2X,F6.2)
  663 FORMAT(1H0,4X,'INTEREST',17X,F7.5,11F7.1,F8.1,2X,F6.2)
      DO 67 I=1,4
      DO 68 J=1,11
   68 SUMP(J)=SUMP(J)+BACOST(I,J)
   67 CONTINUE
      SS=0.
      DO 69 I=1,11
   69 SS=SS+SUMP(I)
      SPER=SS/TMILE
      PERC=SS*100./PCNTEV
      WRITE(NOUT,70)SPER,(SUMP(I),I=1,11),SS,PERC
   70 FORMAT(1H0,2X,'TOTAL BATTERY REPL COST',4X,F7.5,11F7.1,F8.1,2X,
     1F6.2)
      WRITE(NOUT,21)
      WRITE(NOUT,71)
   71 FORMAT(1H0,2X,'OTHER OPERATING COSTS')
      N=N1+1
      DO 72 I=N,21
      SS=0.
      DO 73 J=1,11
      SUMP(J)=0.
   73 SS=SS+OPCOST(I,J)
      SPER=SS/TMILE
      PERC=SS*100./PCNTHV
   72 WRITE(NOUT,42)(OPNAME(I,J),J=1,25),SPER,(OPCOST(I,J),J=1,11),SS,
     1PERC
      DO 74 I=N,21
      DO 75 J=1,11
   75 SUMP(J)=SUMP(J)+OPCOST(I,J)
   74 CONTINUE
      SS=0.
      DO 76 I=1,11
   76 SS=SS+SUMP(I)
      SPER=SS/TMILE
      PERC=SS*100./PCNTEV
      WRITE(NOUT,77)SPER,(SUMP(I),I=1,11),SS,PERC
   77 FORMAT(1H0,2X,'TOTAL OTHER OPERATING COST',1X,F7.5,11F7.1,F8.1,
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     12X,F6.2)
      DO 80 I=1,11
   80 SUMP(I)=PROPUL(I)
      DO 81 I=1,4
      DO 82 J=1,11
   82 SUMP(J)=SUMP(J)+BICCST(I,J)
   81 CONTINUE
      DO 83 I=1,N1
      DO 84 J=1,11
   84 SUMP(J)=SUMP(J)+CICCST(I,J)
   83 CONTINUE
      SS=0.
      DO 85 I=1,11
   85 SS=SS+SUMP(I)
      SPER=SS/TMILE
      PERC=SS*100./BCNTHV
      WRITE(NOUT,86) SPER,(SUMP(I),I=1,11),SS,PERC
   86 FORMAT(1H0,'TOTAL OPERATING COST',9X,F7.5,11F7.1,F8.1,2X,F6.2)
      IF(RDCOST.EQ.0.) GO TO 559
      WRITE(NOUT,21)
      DO 560 I=1,11
  560 SUMP(I)=0.
      SUMP(1)=RDCOST
      SPER=RDCOST/TMILE
      PERC=RDCOST*100./BCNTHV
      WRITE(NOUT,87)IAMORT,SPER,(SUMP(I),I=1,11),RDCOST,PERC
   87 FORMAT(1H0,'R+D COST AMORT (',I7,' YRS)',1X,F7.5,11F7.1,F8.1,2X,
     1F6.2)
  559 WRITE(NOUT,88)
   88 FORMAT(1H ,37X,11(6('-'),1X),7('-'),1X,8('-'))
      SS=0.
      DO 89 I=1,11
   89 SS=SS+SUMLCC(I)
      SPER=SS/TMILE
      PERC=100.
      WRITE(NOUT,90)SPER,(SUMLCC(I),I=1,11),SS,PERC
   90 FORMAT(1H0,'PRESENT VALUE OF TOTAL LCC',3X,F7.5,11F7.1,F8.1,2X,
     1F6.2)
      WRITE(NOUT,91)
   91 FORMAT(1H0,130('-'))
C     READ IN LCC AND PETROLEUM COSTS FOR ICE
      READ(NIN,92)PCCICE,PETICE
   92 FORMAT(2F10.3)
      BENEF=PETICE-PNTHV
      COST=(BCNTHV-PNTHV)-(PCCICE-PETICE)
      BENET=BENEF-COST
      WRITE(NOUT,93)PETICE,PNTHV,BENEF
   93 FORMAT(1H0,'BENEFIT PER NTHV =',F9.2,' - ',F9.2,' = ',F9.2)
      WRITE(NOUT,94)BCNTHV,PNTHV,PCCICE,PETICE,COST
   94 FORMAT(1H0,'COST OF ACCRUING THIS BENEFIT PER NTHV = (',F9.2,
     1' - ',F9.2,' ) - (',F9.2,' - ',F9.2,' ) = ',F9.2)
      WRITE(NOUT,95)BENET
   95 FORMAT(1H0,'NET BENEFIT PER NTHV =',F9.2)
      WRITE(NOUT,91)
      RETURN
      END
//LKED.SYSLMOD DD UNIT=3350,VOL=SER=[illegible],DISP=(NEW,CATLG),
// DSN=WYL.[illegible]734.[illegible]4200.LCCLIB(LCC),SPACE=(TRK,(20,20,1),RLSE)
```

INPUT DATA FOR THE REFERENCE
ICE VEHICLE IN MISSION A

ORIGINAL PAGE IS
OF POOR QUALITY

```
700   JPL NEAR TERM HYBRID PASSENGER VEHICLE DEVELOPMENT PROGRAM-PHASE I MARCH 1979
800           1          1       1978        1985           5    100000 MARCH 28 1979REFICE
900      15
1000  FRAME AND BODY STRUCTURE       266.3 1.1800E+00                              $/KG
1100  REMOVABLE PANELS               146.0 6.0600E+00                              $/KG
1200  BASIC BODY                     226.5 2.3800E+00                              $/KG
1300  SUSPENSION SYSTEM              65.6  1.7400E+00                              $/KG
1400  BRAKE SYSTEM                   75.9  1.8100E+00                              $/KG
1500  STEERING SYSTEM                30.0  4.6700E+00                              $/KG
1600  TIRES                          54.3  1.4600E+00                              $/KG
1700  WHEELS                         41.1  1.1100E+00                              $/KG
1800  RESTRAINTS                     14.2  5.2000E+00                              $/KG
1900  EMISSIONS EQUIPMENT            18.2  2.8500E+00                              $/KG
2000  AIR CONDITIONING               22.3  1.1180E+01                              $/KG
2100  TRANSMISSION                   71.4  1.7200E+00                              $/KG
2200  DRIVE SYSTEM                   57.2  2.1400E+00                              $/KG
2300  HEAT ENGINE                    183.9 1.2900E+00                              $/KG
2400  VEHICLE ASSEMBLY                     1.6000E-01                              $/KG
2500  MARKUP FACTOR                        2.0000E+00
2600  0.05      0.12      48.0      0.03      0.02
2700  BATTERY REPLACEMENT OEM COST
2800  BATTERY MARKUP FACTOR
2900
3000
3100       2 29000 24300 21570 19640 18190 16900 15780 14810 14000 13360
3200  HEAT ENGINE                          16000 3.0      16.       25.
3300  GEARBOX                              80000 2.0      16.       30.
3400     1     1     5
3500  GASOLINE                 $/LITER
3600  .251 .259 .266 .274 .281 .289 .292 .294 .297 .300 KM/LITER  10.74
3700  REPAIRS                  0.0069    $/KM
3800  TIRE REPL EVERY 50000 KM 0.0023    $/KM
3900  INSURANCE                0.0090    $/KM
4000  ANNUAL REG. AND LICENSE  0.0018    $/KM
4100  ACCESSORIES              0.0019    $/KM
4200  GARAGING,PARKING,TOLLS   0.0152    $/KM
4300
```

REFERENCE ICE VEHICLE LIFE CYCLE COST
IN MISSION A

JPL NEAR TERM HYBRID PASSENGER VEHICLE DEVELOPMENT PROGRAM-PHASE I MARCH 1979

VEHICLE ACQUISITION COST BREAKDOWN

(1978 $)

ANNUAL PRODUCTION RATE 100000 VEHICLES/YR FOR 5 YEARS

RUN NO. 1

DATE MARCH 28 1979REFICE

SYSTEM PACKAGE NO. 1

W=CURB WEIGHT

MANUFACTURING COSTS	WEIGHT (KG)	COST ($)	COST/KG ($/KG)	% OF MANUF. COSTS	UNIT COST ESTIMATE RELATIONSHIP	FUNCTION	UNITS
FRAME AND BODY STRUCTURE	266.3	314.23	1.18	9.48	C= 0.1180E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
REMOVABLE PANELS	146.0	884.76	6.06	26.68	C= 0.6060E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
BASIC BODY	226.5	539.07	2.38	16.26	C= 0.2380E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
SUSPENSION SYSTEM	65.6	114.14	1.74	3.44	C= 0.1740E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
BRAKE SYSTEM	75.9	137.38	1.81	4.14	C= 0.1810E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
STEERING SYSTEM	30.0	140.10	4.67	4.23	C= 0.4670E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
TIRES	54.3	79.28	1.46	2.39	C= 0.1460E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
WHEELS	41.1	45.62	1.11	1.38	C= 0.1110E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
RESTRAINTS	14.2	73.84	5.20	2.23	C= 0.5200E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
EMISSIONS EQUIPMENT	18.2	51.87	2.85	1.56	C= 0.2850E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
AIR CONDITIONING	22.3	249.31	11.18	7.52	C= 0.1118E+02+(0.0)*W+(0.0)*W*W	W=W	$/KG
TRANSMISSION	71.4	122.81	1.72	3.70	C= 0.1720E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
DRIVE SYSTEM	57.2	122.41	2.14	3.69	C= 0.2140E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
HEAT ENGINE	183.9	237.23	1.29	7.15	C= 0.1290E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
VEHICLE ASSEMBLY		203.66	0.16	6.14	C= 0.1600E+00+(0.0)*W+(0.0)*W*W	W=W	$/KG
TOTALS	1272.9	3315.72	2.60	100.00			

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	TOTAL
PURCHASE PRICE (MF= 2.00)	1657.86	1657.86	1657.86	1657.86	0.0	0.0	0.0	0.0	0.0	0.0		6631.44
SALES TAXES (5.00 %)	331.57	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		331.57
INTEREST (12.00 % AT 48 MOS)	525.44	525.44	525.44	525.44	0.0	0.0	0.0	0.0	0.0	0.0		2101.76

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SALVAGE VALUE OF VEH (5.00 %)											-331.57	-331.57
TOTALS	2514.87	2183.30	2183.30	2183.30	0.0	0.0	0.0	0.0	0.0	0.0	-331.57	8733.19
PRESENT VALUE (2.00 %)	2465.56	2098.52	2057.37	2017.03	0.0	0.0	0.0	0.0	0.0	0.0	-266.67	8371.80

SALVAGE VALUE OF VEH (5.00 %)										-331.57	-331.57
TOTALS	2514.87	2183.30	2183.30	2183.30	0.0	0.0	0.0	0.0	0.0	0.0	-331.57	8733.19
PRESENT VALUE (2.00 %)	2465.56	2098.52	2057.37	2017.03	0.0	0.0	0.0	0.0	0.0	0.0	-266.67	8371.80

PROPULSION SYSTEM MAINTENANCE COSTS

(1978 $)

RUN NO. 1

DATE . MARCH 28 1979REPICE

SYSTEM PACKAGE NO. 1

COMPONENT NAME	SCHEDULED MAINT INTERVAL (KM)	MEAN TIME TO REPAIR/ REPLACE/INSPECT (HRS)	LABOR RATE ($/HR)	PARTS COST/MAINT INTERVAL ($)	LIFETIME TOTAL COST ($)
HEAT ENGINE	16000	3.00	16.00	25.00	803.00
GEARBOX	80000	2.00	16.00	30.00	124.00

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	TOTAL
ANNUAL MILEAGE	29000	24300	21570	19640	18190	16900	15780	14810	14000	13360	187550
PROPUL SYS TOTAL MAINT COSTS	73.00	146.00	73.00	135.00	146.00	73.00	73.00	135.00	0.0	73.00	927.00
PRESENT VALUE (2.00 %)	71.57	140.33	68.79	124.72	132.24	64.82	63.55	115.22	0.0	59.89	841.13

JPL NEAR TERM HYBRID PASSENGER VEHICLE DEVELOPMENT PROGRAM-PHASE I MARCH 1979

TOTAL OPERATING COSTS

(1978 $)

RUN NO. 1

DATE MARCH 28 1979REFICE

SYSTEM PACKAGE NO. 1

	UNIT COST	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	TOTAL
ANNUAL MILEAGE	KM	29000	24300	21570	19640	18190	16900	15780	14810	14000	13360	187550
GASOLINE	$/LITER	0.251	0.259	0.266	0.274	0.281	0.289	0.292	0.294	0.297	0.300	
OPERATING COSTS												
ENERGY												
GASOLINE	10.74000 KM/LITER	677.7	586.0	534.2	501.1	475.9	454.8	429.0	405.4	387.2	373.2	4824.5
TOTAL ENERGY COSTS		677.7	586.0	534.2	501.1	475.9	454.8	429.0	405.4	387.2	373.2	4824.5
MAINTENANCE AND REPAIR												
PROPULSION SYSTEM MAINT	-	73.0	146.0	73.0	135.0	146.0	73.0	73.0	135.0	0.0	73.0	927.0
REPAIRS	0.00690 $/KM	200.1	167.7	148.8	135.5	125.5	116.6	108.9	102.2	96.6	92.2	1294.1
TOTAL M+R COSTS		273.1	313.7	221.8	270.5	271.5	189.6	181.9	237.2	96.6	165.2	2221.1
BATTERY REPLACEMENT												
PURCHASE PRICE(0.0 $)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SALES TAXES (0.0 %)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INTEREST(0.0 % AT 0 MOS)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SALVAGE VALUE (0.0 %)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL BAT REPL COSTS		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OTHER OPERATING COSTS												
TIRE REPL EVERY 50000 KM	0.00230 $/KM	66.7	55.9	49.6	45.2	41.8	38.9	36.3	34.1	32.2	30.7	431.4
INSURANCE	0.00900 $/KM	261.0	218.7	194.1	176.8	163.7	152.1	142.0	133.3	126.0	120.2	1687.9
ANNUAL REG. AND LICENSE	0.00180 $/KM	52.2	43.7	38.8	35.4	32.7	30.4	28.4	26.7	25.2	24.0	337.6
ACCESSORIES	0.00190 $/KM	55.1	46.2	41.0	37.3	34.6	32.1	30.0	28.1	26.6	25.4	356.3
GARAGING,PARKING,TOLLS	0.01520 $/KM	440.8	369.4	327.9	298.5	276.5	256.9	239.9	225.1	212.8	203.1	2850.8
TOTAL OTHER OP COSTS		875.8	733.9	651.4	593.1	549.3	510.4	476.6	447.3	422.8	401.5	5664.0

TOTAL OPERATING COSTS	1826.6	1633.5	1407.5	1364.7	1296.0	1154.7	1087.5	1089.9	906.5	941.0	11782.6
PRESENT VALUE (2.00 %)	1790.8	1570.1	1326.3	1260.8	1174.5	1025.4	946.7	930.2	758.6	772.6	9476.4

JPL NEAR TERM HYBRID PASSENGER VEHICLE DEVELOPMENT PROGRAM-PHASE I MARCH 1979

PRESENT VALUE OF TOTAL LIFE CYCLE COSTS

(1978 $)

DISCOUNT RATE= 2.00 %

RUN NO. 1

DATE MARCH 28 1979REFICE

SYSTEM PACKAGE NO. 1

	$/KM	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	TOTAL	% OF LCC
ACQUISITION COSTS														
PURCHASE PRICE	0.03366	1625.4	1593.5	1562.2	1531.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6312.7	31.68
SALES TAXES	0.00173	325.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	325.1	1.63
INTEREST	0.01067	515.1	505.0	495.1	485.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2000.7	10.04
SALVAGE VALUE OF VEHICLE	0.09142	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-266.7	-266.7	1.34
TOTAL ACQUISITION COST	0.04464	2465.6	2098.5	2057.4	2017.0	0.0	0.0	0.0	0.0	0.0	0.0	-266.7	8371.8	42.01
OPERATING COSTS														
ENERGY COSTS														
GASOLINE	0.02335	664.5	563.3	503.4	462.9	431.1	403.8	373.5	346.0	324.0	306.1	0.0	4378.5	21.97
TOTAL ENERGY COST	0.02335	664.5	563.3	503.4	462.9	431.1	403.8	373.5	346.0	324.0	306.1	0.0	4378.5	21.97
MAINTENANCE + REPAIR COSTS														
PROPULSION SYSTEM MAINT	0.00448	71.6	140.3	68.8	124.7	132.2	64.8	63.6	115.2	0.0	59.9	0.0	841.1	4.22
REPAIRS	0.00628	196.2	161.2	140.2	125.2	113.7	103.5	94.8	87.2	80.8	75.6	0.0	1178.5	5.91
TOTAL MAINT + REPAIR COST	0.01077	267.7	301.5	209.0	249.9	245.9	168.4	158.3	202.4	80.8	135.5	0.0	2019.6	10.13
BATTERY REPLACEMENT COSTS														
BATTERY PURCHASE PRICE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SALES TAXES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INTEREST	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SALVAGE VALUE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL BATTERY REPL COST	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OTHER OPERATING COSTS														
TIRE REPL EVERY 50000 KM	0.00209	65.4	53.7	46.7	41.7	37.9	34.5	31.6	29.1	26.9	25.2	0.0	392.8	1.97
INSURANCE	0.00820	255.9	210.2	182.9	163.3	148.3	135.1	123.6	113.8	105.4	98.6	0.0	1537.1	7.71
ANNUAL REG. AND LICENSE	0.00164	51.2	42.0	36.6	32.7	29.7	27.0	24.7	22.8	21.1	19.7	0.0	307.4	1.54

ACCESSORIES	0.00173	54.0	44.4	38.6	34.5	31.3	28.5	26.1	24.0	22.3	20.8	0.0	324.5	1.63
GARAGING,PARKING,TOLLS	0.01384	432.2	355.0	303.0	275.8	250.4	228.1	208.8	192.1	178.1	166.6	0.0	2596.0	13.03
TOTAL OTHER OPERATING COST	0.02750	858.6	705.4	613.8	548.0	497.6	453.2	414.9	381.7	353.8	331.0	0.0	5157.9	25.88
TOTAL OPERATING COST	0.06162	1790.8	1570.1	1326.3	1260.8	1174.5	1025.4	946.7	930.2	758.6	772.6	0.0	11556.0	57.99
PRESENT VALUE OF TOTAL LCC	0.10625	4256.4	3668.6	3383.7	3277.8	1174.5	1025.4	946.7	930.2	758.6	772.6	-266.7	19927.8	100.00

BENEFIT PER NTHV = 0.0 - 4378.51 = -4378.51

COST OF ACCRUING THIS BENEFIT PER NTHV = (19927.82 - 4378.51) - (0.0 - 0.0) = 15549.31

NET BENEFIT PER NTHV =-19927.82

INPUT DATA FOR THE BASELINE
NTHV IN MISSION A

ORIGINAL PAGE IS
OF POOR QUALITY

```
700    JPL NEAR TERM HYBRID PASSENGER VEHICLE DEVELOPMENT PROGRAM-PHASE I MARCH 1979
800          2        1        1978        1985         5    100000 MARCH 28 1979
900       21
1000   FRAME AND BODY STRUCTURE       298.0 1.1800E+00                       $/KG
1100   REMOVABLE PANELS               124.6 6.0600E+00                       $/KG
1200   BASIC BODY                     170.0 2.3800E+00                       $/KG
1300   SUSPENSION SYSTEM              78.4  1.7400E+00                       $/KG
1400   BRAKE SYSTEM                   88.3  1.8100E+00                       $/KG
1500   STEERING SYSTEM                27.3  4.6700E+00                       $/KG
1600   TIRES                          63.0  1.4600E+00                       $/KG
1700   WHEELS                         45.4  1.1100E+00                       $/KG
1800   RESTRAINTS                     14.2  5.2000E+00                       $/KG
1900   AIR CONDITIONING               22.3  1.1880E+01                       $/KG
2000   TRANSMISSION                   54.5  1.7200E+00                       $/KG
2100   DRIVE SYSTEM                   61.9  2.1400E+00                       $/KG
2200   HEAT ENGINE                    118.2 1.6100E+00                       $/KG
2300   MOTOR                          56.8  3.9500E+00                       $/KG
2400   CONTROLLER                     5.0   2.6600E+01                       $/KW   1.
2500   CHARGER                        5.0   1.0640E+01                       $/KW   2.
2600   BATTERY,72V,LEAD/ACID          336.4 1.8700E+00                       $/KG
2700   POWER HARNESS                  22.7  2.7000E+00                       $/KG
2800   BATTERY TRAY                   34.1  2.3800E+00                       $/KG
2900   MICROPROCESSOR,SENSORS         17.0  7.0600E+00                       $/KG
3000   VEHICLE ASSEMBLY                     1.6000E-01                       $/KG
3100   MARK-UP FACTOR                       2.0000E+00
3200   0.05      0.12       48.       0.05      0.02
3300   BATTERY REPLACEMENT OEM COST   336.4 1.8700E+00
3400   BATTERY MARK-UP FACTOR         2.74  2.0000E+00
3500   0.05      0.12       26.0      0.10
3600      3    5    6    5 0.1
3700   PHASE I PROGRAM                48000.     30.0      0.        0.1
3800   PHASE II PROGRAM               800000.    25.0      0.        0.1
3900   MANUFACTURE OF R&D PROTOTYPES                       300000.   0.1
4000        6 29000 24300 21570 19640 18190 16900 15780 14810 14000 13360
4100   HEAT ENGINE                         48000 3.0       16.       25.
4200   MOTOR                               40000 1.0       16.       15.
4300   GEARBOX                             80000 2.0       16.       30.
4400   CONTROLLER                         160000 1.0       16.       20.
4500   BATTERY CHARGER                    160000 1.0       16.       20.
4600   BATTERY                              2000 0.25      16.       0.2
4700      2    1    5
4800   DIESEL FUEL                $/LITER
4900   .235 .242 .249 .256 .263 .270 .273 .275 .278 .280 KM/LITER   34.42
5000   ELECTRICITY                $/KWHR
5100   .0420.0426.0432.0438.0444.0450.0456.0462.0468.0474KM/KWHR    5.77
5200   REPAIRS                    0.0077    $/KM
5300   TIRE REPL EVERY 50000 KM   0.0023    $/KM
5400   INSURANCE                  0.0099    $/KM
5500   ANNUAL REG. AND LICENSE    0.0018    $/KM
5600   ACCESSORIES                0.0019    $/KM
5700   GARAGING,PARKING,TOLLS     0.0152    $/KM
5800   19927.82  4378.51
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BASELINE NTHV LIFE CYCLE COST
IN MISSION A

JPL NEAR TERM HYBRID PASSENGER VEHICLE DEVELOPMENT PROGRAM-PHASE I MARCH 1979

VEHICLE ACQUISITION COST BREAKDOWN

(1978 $)

ANNUAL PRODUCTION RATE 100000 VEHICLES/YR FOR 5 YEARS

RUN NO. 2

DATE MARCH 28 1979

SYSTEM PACKAGE NO. 1

W=CURB WEIGHT

MANUFACTURING COSTS	WEIGHT (KG)	COST ($)	COST/KG ($/KG)	% OF MANUF. COSTS	UNIT COST ESTIMATE RELATIONSHIP	FUNCTION	UNITS
FRAME AND BODY STRUCTURE	298.0	351.64	1.18	8.26	C= 0.1180E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
REMOVABLE PANELS	124.6	755.08	6.06	17.73	C= 0.6060E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
BASIC BODY	170.0	404.60	2.38	9.50	C= 0.2380E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
SUSPENSION SYSTEM	70.4	116.42	1.74	3.20	C= 0.1740E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
BRAKE SYSTEM	88.3	159.02	1.81	3.75	C= 0.1810E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
STEERING SYSTEM	27.3	127.49	4.67	2.99	C= 0.4670E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
TIRES	63.0	91.98	1.46	2.16	C= 0.1460E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
WHEELS	45.4	50.39	1.11	1.18	C= 0.1110E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
RESTRAINTS	14.2	73.84	5.20	1.73	C= 0.5200E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
AIR CONDITIONING	22.3	264.92	11.88	6.22	C= 0.1188E+02+(0.0)*W+(0.0)*W*W	W=W	$/KG
TRANSMISSION	53.5	91.74	1.72	2.20	C= 0.1720E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
DRIVE SYSTEM	61.9	132.47	2.14	3.11	C= 0.2140E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
HEAT ENGINE	118.2	190.30	1.61	4.47	C= 0.1610E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
MOTOR	56.8	224.36	3.95	5.27	C= 0.3950E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
CONTROLLER	5.0	26.60	5.32	0.62	C= 0.2660E+02+(0.0)*W+(0.0)*W*W	W=W	$/KW
CHARGER	5.0	21.28	4.26	0.50	C= 0.1064E+02+(0.0)*W+(0.0)*W*W	W=W	$/KW
BATTERY,72V,LEAD/ACID	336.4	629.07	1.87	14.77	C= 0.1870E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
POWER HARNESS	22.7	61.29	2.70	1.44	C= 0.2700E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
BATTERY TRAY	34.1	81.16	2.38	1.91	C= 0.2380E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
MICROPROCESSOR,SENSORS	17.0	120.02	7.06	2.82	C= 0.7060E+01+(0.0)*W+(0.0)*W*W	W=W	$/KG
VEHICLE ASSEMBLY		262.90	0.16	6.17	C= 0.1600E+00+(0.0)*W+(0.0)*W*W	W=W	$/KG
TOTALS	1643.1	4259.36	2.59	100.00			

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	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	TOTAL
PURCHASE PRICE (HF= 2.00)	2129.68	2129.68	2129.68	2129.68	0.0	0.0	0.0	0.0	0.0	0.0		8518.72
SALES TAXES (5.00 %)	425.94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		425.94
INTEREST (12.00 % AT 48 MOS)	674.98	674.98	674.98	674.98	0.0	0.0	0.0	0.0	0.0	0.0		2699.91
SALVAGE VALUE OF VEH (5.00 %)											-425.94	-425.94
TOTALS	3230.59	2804.65	2804.65	2804.65	0.0	0.0	0.0	0.0	0.0	0.0	-425.94	11218.62
PRESENT VALUE (2.00 %)	3167.25	2695.75	2682.89	2591.07	0.0	0.0	0.0	0.0	0.0	0.0	-342.57	10754.39

JPL NEAR TERM HYBRID PASSENGER VEHICLE DEVELOPMENT PROGRAM-PHASE I MARCH 1979

RESEARCH AND DEVELOPMENT COST SUMMARY

(1978 $)

NUMBER OF R+D VEHICLES= 5

RUN NO. 2

DATE MARCH 28 1979

SYSTEM PACKAGE NO. 1

R+D COST ELEMENT	MAN-HOURS (HRS)	COMPOSITE RATE ($/HR)	MAN-HOUR RELATED COSTS ($)	CONTRACTOR PROFIT ($)	TOTAL COST ($)
PHASE I PROGRAM	48000.	30.00	0.	144000.	1584000.
PHASE II PROGRAM	800000.	25.00	0.	2000000.	22000000.
MANUFACTURE OF R&D PROTOTYPES	0.	0.0	300000.	30000.	330000.
TOTALS	848000.		300000.	2174000.	23914000.

PRESENT VALUE OF R+D COSTS AT 10.00 % DISCOUNT RATE AND FOR 6 YEARS OF EQUAL ANNUAL COSTS IS 33826800. $

R+D AMORTIZATION PER NTHV VEHICLE IS 67.65 $ FOR 500000 VEHICLES

PROPULSION SYSTEM MAINTENANCE COSTS

(1978 $)

RUN NO. 2

DATE MARCH 28 1979

SYSTEM PACKAGE NO. 1

COMPONENT NAME	SCHEDULED MAINT INTERVAL (KM)	MEAN TIME TO REPAIR/ REPLACE/INSPECT (HRS)	LABOR RATE ($/HR)	PARTS COST/MAINT INTERVAL ($)	LIFETIME TOTAL COST ($)
HEAT ENGINE	80000	3.00	16.00	25.00	219.00
MOTOR	40000	1.00	16.00	15.00	124.00
GEARBOX	80000	2.00	16.00	30.00	124.00
CONTROLLER	160000	1.00	16.00	20.00	36.00
BATTERY CHARGER	160000	1.00	16.00	20.00	36.00
BATTERY	2000	0.25	16.00	0.28	390.69

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	TOTAL
ANNUAL MILEAGE	29000	24300	21570	19640	18190	16900	15780	14810	14000	13360	187550
PROPUL SYS TOTAL MAINT COSTS	58.80	154.40	46.20	135.00	110.80	64.60	106.60	198.60	29.40	25.20	929.60
PRESENT VALUE (2.00 %)	57.65	148.40	43.54	124.72	100.36	57.36	92.80	169.50	24.60	20.67	839.60

JPL NEAR TERM HYBRID PASSENGER VEHICLE DEVELOPMENT PROGRAM-PHASE I MARCH 1979

TOTAL OPERATING COSTS

(1978 $)

RUN NO. 2

DATE MARCH 28 1979

SYSTEM PACKAGE NO. 1

	UNIT COST	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	TOTAL
ANNUAL MILEAGE	KM	29000	24300	21570	19640	18190	16900	15780	14810	14000	13360	187550
DIESEL FUEL	$/LITER	0.235	0.242	0.249	0.256	0.263	0.270	0.273	0.275	0.278	0.280	
ELECTRICITY	$/KWHR	0.042	0.043	0.043	0.044	0.044	0.045	0.046	0.046	0.047	0.047	
OPERATING COSTS												
ENERGY												
DIESEL FUEL	33.67000 KM/LITER	202.4	174.7	159.5	149.3	142.1	135.5	127.9	121.0	115.6	111.1	1439.1
ELECTRICITY	5.50000 KM/KWHR	221.5	188.2	169.4	156.4	146.8	138.3	130.8	124.4	119.1	115.1	1510.1
TOTAL ENERGY COSTS		423.9	362.9	328.9	305.7	288.9	273.8	258.8	245.4	234.7	226.2	2949.2
MAINTENANCE AND REPAIR												
PROPULSION SYSTEM MAINT	-	58.8	154.4	46.2	135.0	110.8	64.6	106.6	198.6	29.4	25.2	929.6
REPAIRS	0.00770 $/KM	223.3	187.1	166.1	151.2	140.1	130.1	121.5	114.0	107.8	102.9	1444.1
TOTAL M+R COSTS		282.1	341.5	212.3	286.2	250.9	194.7	228.1	312.6	137.2	128.1	2373.7
BATTERY REPLACEMENT												
PURCHASE PRICE(1258.1 $)		0.0	0.0	145.2	580.7	532.3	338.7	580.7	338.7	532.3	580.7	3629.2
SALES TAXES (5.00 %)		0.0	0.0	62.9	0.0	0.0	62.9	0.0	0.0	62.9	0.0	188.7
INTEREST(12.00% AT 26 MOS)		0.0	0.0	28.2	112.8	103.4	65.8	112.8	65.8	103.4	112.8	704.7
SALVAGE VALUE (10.00 %)		0.0	0.0	-125.8	0.0	0.0	-125.8	0.0	0.0	-125.8	0.0	-377.4
TOTAL BAT REPL COSTS		0.0	0.0	110.5	693.4	635.6	341.6	693.4	404.5	572.7	693.4	4145.2
OTHER OPERATING COSTS												
TIRE REPL EVERY 50000 KM	0.00230 $/KM	66.7	55.9	49.6	45.2	41.8	38.9	36.3	34.1	32.2	30.7	431.4
INSURANCE	0.00990 $/KM	287.1	240.6	213.5	194.4	180.1	167.3	156.2	146.6	138.6	132.3	1856.7
ANNUAL REG. AND LICENSE	0.00180 $/KM	52.2	43.7	38.8	35.4	32.7	30.4	28.4	26.7	25.2	24.0	337.6
ACCESSORIES	0.00190 $/KM	55.1	46.2	41.0	37.3	34.6	32.1	30.0	28.1	26.6	25.4	356.3

GARAGING,PARKING,TOLLS	0.01520 $/KM	440.8	369.4	327.9	298.5	276.5	256.9	239.9	225.1	212.8	203.1	2850.8
TOTAL OTHER OP COSTS		901.9	755.7	670.8	610.8	565.7	525.6	490.8	460.6	435.4	415.5	5832.8
TOTAL OPERATING COSTS		1607.9	1460.1	1322.5	1896.2	1741.1	1335.7	1671.1	1423.1	1380.1	1463.2	10226.1
PRESENT VALUE (2.00 %)		1576.3	1403.4	1246.2	1751.8	1577.0	1186.1	1454.8	1214.6	1154.8	1200.4	8224.6

JPL NEAR TERM HYBRID PASSENGER VEHICLE DEVELOPMENT PROGRAM-PHASE I MARCH 1979

PRESENT VALUE OF TOTAL LIFE CYCLE COSTS

(1978 $)

DISCOUNT RATE= 2.00 %

RUN NO. 2

DATE MARCH 28 1979

SYSTEM PACKAGE NO. 1

	$/KM	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	TOTAL	% OF LCC
ACQUISITION COSTS														
PURCHASE PRICE	0.04324	2087.9	2047.0	2006.8	1967.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8109.2	32.98
SALES TAXES	0.00223	417.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	417.6	1.70
INTEREST	0.01370	661.7	648.8	636.0	623.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2570.1	10.45
SALVAGE VALUE OF VEHICLE	0.00183	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-342.6	-342.6	1.39
TOTAL ACQUISITION COST	0.05734	3167.2	2695.7	2642.9	2591.1	0.0	0.0	0.0	0.0	0.0	0.0	-342.6	10754.4	43.74
OPERATING COSTS														
ENERGY COSTS														
DIESEL FUEL	0.00696	198.4	167.9	150.3	130.0	128.7	120.3	111.4	103.2	96.7	91.1	0.0	1306.1	5.31
ELECTRICITY	0.00732	217.1	180.9	159.7	144.5	133.0	122.8	113.9	106.2	99.7	94.5	0.0	1372.2	5.58
TOTAL ENERGY COST	0.01428	415.5	348.8	310.0	282.5	261.7	243.1	225.3	209.4	196.4	185.6	0.0	2678.3	10.89
MAINTENANCE + REPAIR COSTS														
PROPULSION SYSTEM MAINT	0.00448	57.6	148.4	43.5	124.7	100.4	57.4	92.8	169.5	24.6	20.7	0.0	839.6	3.41
REPAIRS	0.00701	218.9	179.8	156.5	139.7	126.9	115.6	105.8	97.3	90.2	84.4	0.0	1315.1	5.35
TOTAL MAINT + REPAIR COST	0.01149	276.6	328.2	200.0	264.4	227.2	172.9	198.6	266.8	114.8	105.1	0.0	2154.7	8.76
BATTERY REPLACEMENT COSTS														
BATTERY PURCHASE PRICE	0.01692	0.0	0.0	136.8	536.5	482.1	300.8	505.5	289.1	445.4	476.4	0.0	3172.5	12.90
SALES TAXES	0.00089	0.0	0.0	59.3	0.0	0.0	55.9	0.0	0.0	52.6	0.0	0.0	167.8	0.68
INTEREST	0.00328	0.0	0.0	26.6	104.2	93.6	58.4	98.2	56.1	86.5	92.5	0.0	616.0	2.51
SALVAGE VALUE	0.00179	0.0	0.0	-118.6	0.0	0.0	-111.7	0.0	0.0	-105.3	0.0	0.0	-335.6	1.36
TOTAL BATTERY REPL COST	0.01931	0.0	0.0	104.1	640.6	575.7	303.3	603.7	345.2	479.2	568.9	0.0	3620.8	14.73
OTHER OPERATING COSTS														
TIRE REPL EVERY 50000 KM	0.00209	65.4	53.7	46.7	41.7	37.9	34.5	31.6	29.1	26.9	25.2	0.0	392.8	1.60
INSURANCE	0.00902	281.5	231.2	201.2	179.6	163.1	148.6	136.0	125.1	116.0	108.5	0.0	1690.8	6.88

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ANNUAL REG. AND LICENSE	0.00164	51.2	42.0	36.6	32.7	29.7	27.0	24.7	22.8	21.1	19.7	0.0	307.4	1.25
ACCESSORIES	0.00173	54.0	44.4	38.6	34.5	31.3	28.5	26.1	24.0	22.3	20.8	0.0	324.5	1.32
GARAGING,PARKING,TOLLS	0.01384	432.2	355.0	309.0	275.8	250.4	228.1	208.8	192.1	178.1	166.6	0.0	2596.0	10.56
TOTAL OTHER OPERATING COST	0.02832	884.2	726.4	632.1	564.3	512.4	466.7	427.2	393.1	364.3	340.9	0.0	5311.6	21.60
TOTAL OPERATING COST	0.07340	1576.3	1403.4	1246.2	1751.8	1577.0	1186.1	1454.8	1214.6	1154.8	1200.4	0.0	13765.4	55.99
R+D COST AMORT (500000 VEH)	0.00036	67.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	67.7	0.28
PRESENT VALUE OF TOTAL LCC	0.13110	4811.2	4099.2	3889.1	4342.9	1577.0	1186.1	1454.8	1214.6	1154.8	1200.4	-342.6	24587.4	100.00

BENEFIT PER MTHV = 4378.51 - 1306.10 = 3072.41

COST OF ACCRUING THIS BENEFIT PER MTHV = (24587.43 - 1306.10) - (19927.82 - 4378.51) = 7732.02

NET BENEFIT PER MTHV = -4659.60

APPENDIX D

OPSTRAT

APPENDIX D

OPSTRAT

The data in Section 11 were obtained from two computer programs: CARSIM (a detailed simulation routine in which the hybrid's performance is assessed each second of a driving cycle) and OPSTRAT.

OPSTRAT produces information about the hybrid's expected fuel consumption over a range of distances. Its results are based on five factors: the probability density of the instantaneous power required to propel a vehicle over a driving cycle, the power demands of accessories, the rate of petroleum consumption as a function of power, the rate of battery consumption as a function of power, and the vehicle's mean speed. Predictions from CARSIM and OPSTRAT correlate well, which makes the combination of their results possible. A listing of OPSTRAT is provided at the end of this appendix.

The theory underlying OPSTRAT is fairly straightforward. Let $\Delta S(p)$ and $\ell(p)$ represent the motor's battery consumption rate over power and the diesel's petroleum consumption rate over power, respectively. Actual relations for a 48.5 kW diesel and a 24 kW motor are shown in Figures D-1 and D-2. Let $f(p)$ be the density of the power output required for a driving cycle. Figures D-3 and D-4 are histograms of such densities for the FUDC and FHDC, respectively. Then the expected rate of petroleum consumption (in units of volume per unit time) is given by

$$E(\ell/hr) = \int_0^{p_{max}} f(p)\ \ell(p)\ dp$$

or

$$E(\ell/hr) = \sum_1^n P(p_i)\ \ell(p_i)$$

for discrete data. Here, $P(p_i)$ is the probability of power p_i. Similarly, the expected battery consumption rate is

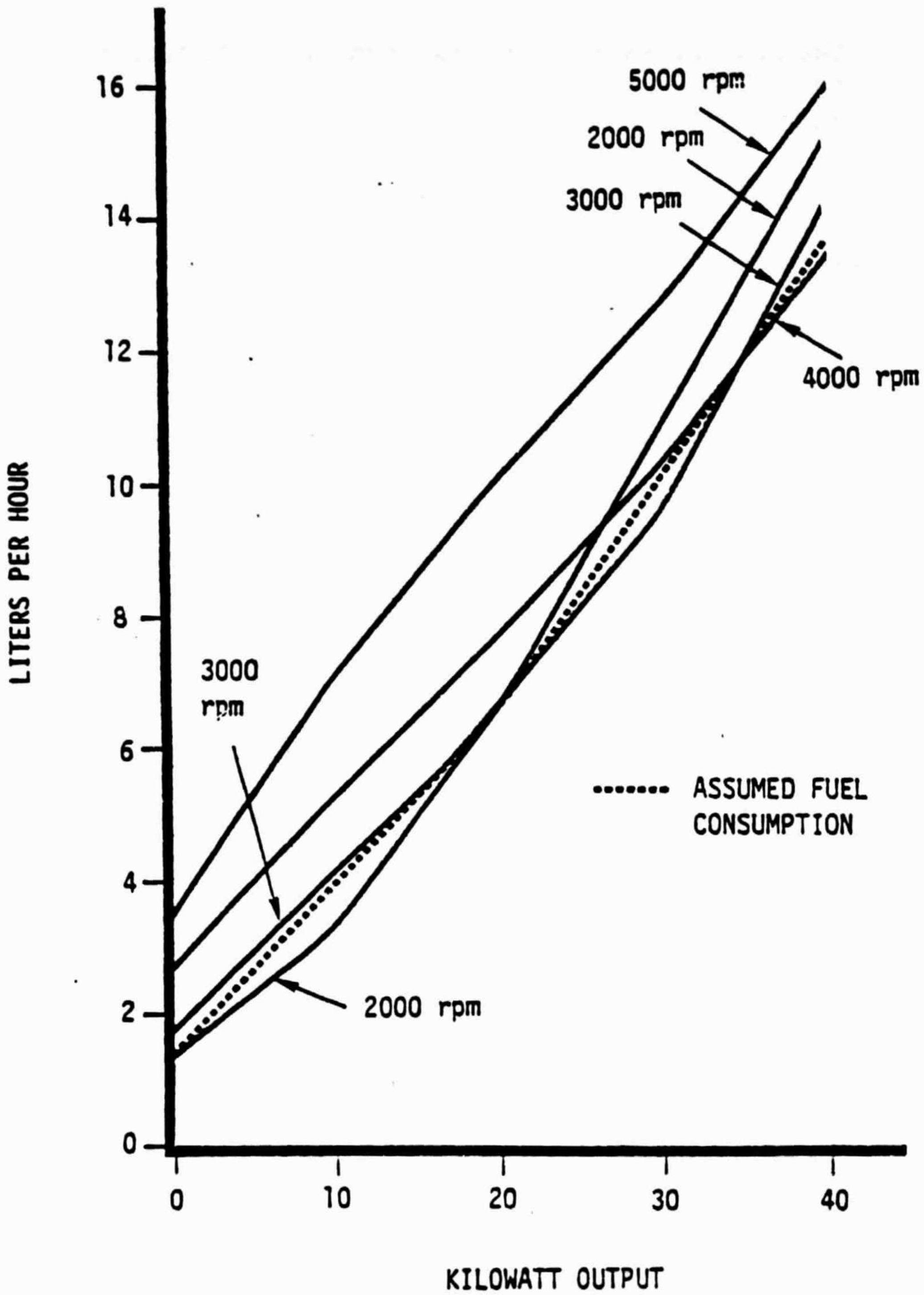

Figure D-1. Petroleum Consumption Over Diesel Power Output: 48.5 kW Diesel

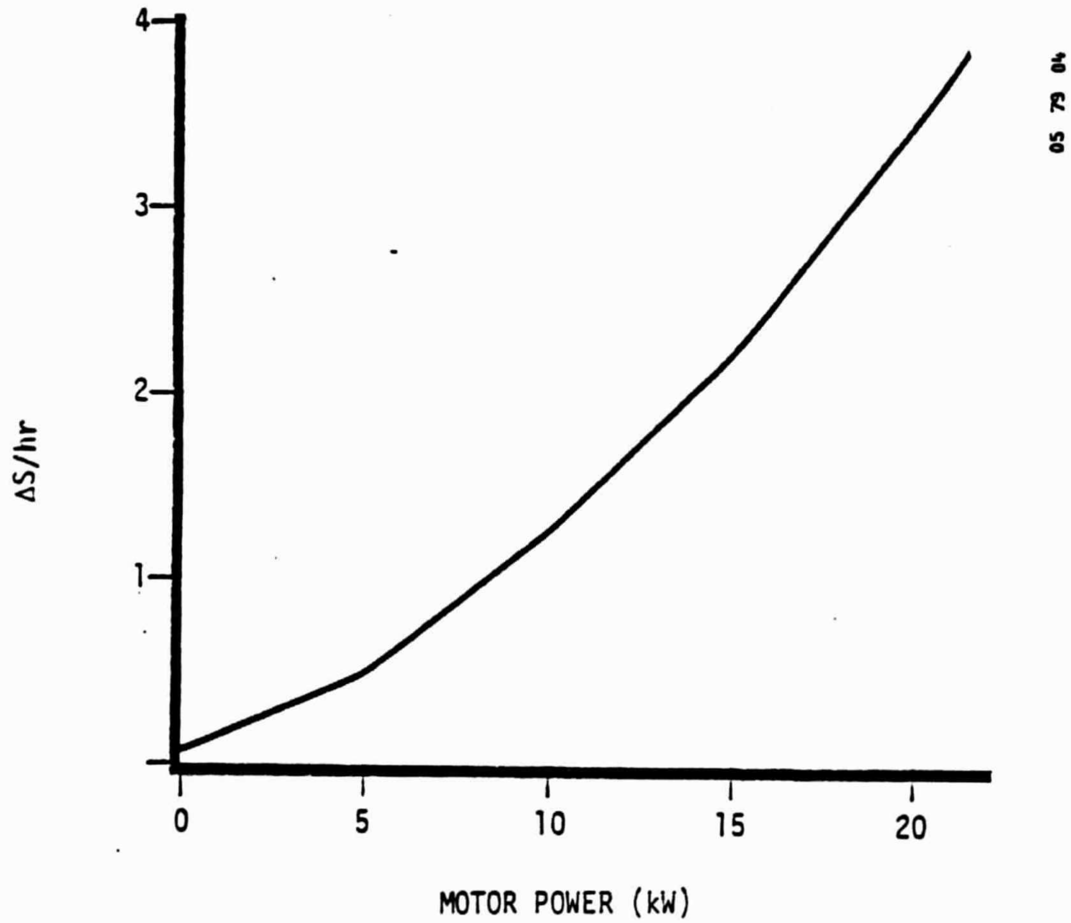

Figure D-2. ΔS/hr Over Motor Power:
24 kW Motor

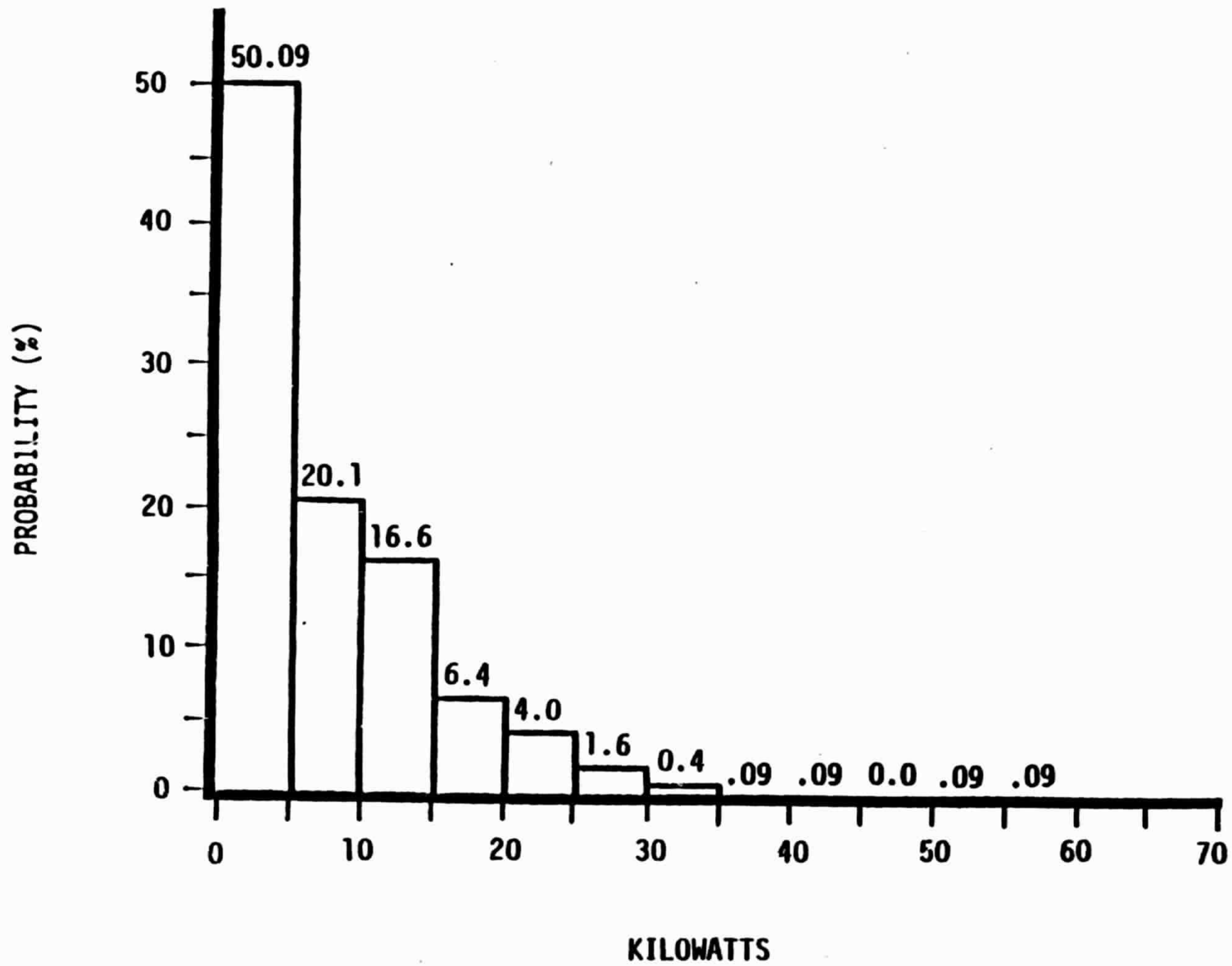

Figure D-3. Distribution of Power: FUDC

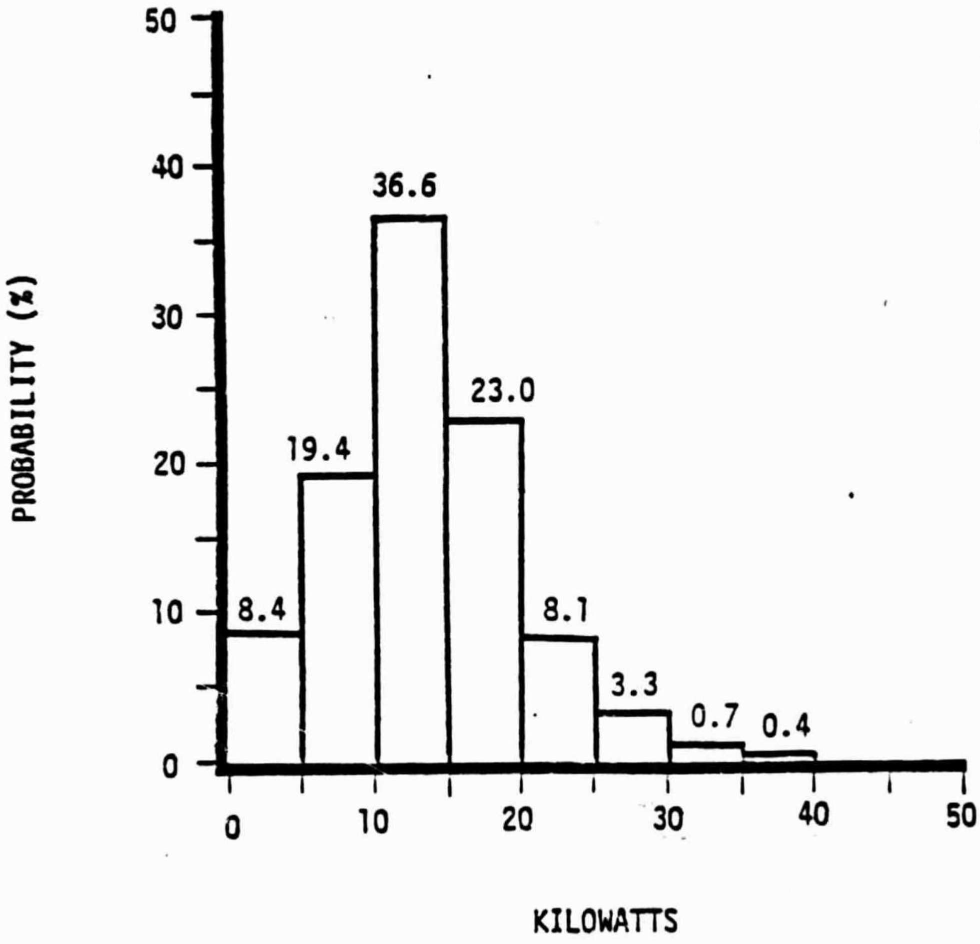

Figure D-4. Distribution of Power: FHDC

$$E(\Delta S/hr) = \int_0^{p_{max}} f(p)\ \Delta S(p)\ dp$$

$$= \sum_1^n P(p_i)\ \Delta S(p_i) \quad .$$

Dividing such consumption rates by mean velocity* produces new rates in units of consumption per unit distance.

OPSTRAT will be expanded to model the effects of strategies other than electric topped by diesel.

---

*"Mean velocity" here is the total distance traveled divided by the time spent in positive, rather than positive and negative, power requirements. The mean velocities for the FUDC and FHDC are 40 and 85 km/hr, respectively.

OPSTRAT PROGRAM LISTING

```
C ****************************************************************
C *                                                              *
C *     Program to evaluate operational strategies using a power *
C *     density approach.                                        *
C *                                                              *
C *                                                              *
C *                                                              *
C ****************************************************************
C
      real f(20), pf(20), xl(20), pl(20), s(20), ps(20), tmp(20)
      real fe(20), pfe(20), fm(20), pfm(20)
      character*10 file, filout
C
      data iy/'y'/
C
    1 format($,10x,a)
    2 format(a10)
    3 format(////5x,'.8 discharge occurs at',f6.1,' kilometers;',
     &f6.2,' liters are consumed.'////)
    4 format(22x,'kilometers',9x,'liters'//)
    6 format(20x,f10.1,9x,f8.2)
    7 format(a1)
C
    8 print 1, 'data file?'
      read 2, file
C
      print 1, 'output file?'
      read 2, filout
C
      open(name=file, unit=1, type='old')
      open(name=filout, unit=2, type='new')
C
C ***
C *
C *   Zero out matrices.
C *
C ***
C
      do 5 i=1,20
      f(i)=0.
      pf(i)=0.
      xl(i)=0.
      pl(i)=0.
      s(i)=0.
      ps(i)=0.
      fe(i)=0.
      pfe(i)=0.
      fm(i)=0.
      pfm(i)=0.
      tmp(i)=0.
    5 continue
C
C ***
C *
C *   Read in data off of file.
C *
C ***
C
```

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```
      read (1,*) npl
      read (1,*) (pl(i), i=1,npl)
      read (1,*) (xl(i), i=1,npl)
c
      read (1,*) nps


      read (1,*) (ps(i), i=1,npl)
      read (1,*) (s(i), i=1,nps)
c
      read (1,*) npf
      read (1,*) (pf(i), i=1,npf)
      read (1,*) (f(i), i=1,npf)
c
c ***
c *
c *   Request run information.
c *
c ***
c
      print 1, 'maximum motor power?'
      read *, pmax
c
      print 1, 'accessory power demand?'
      read *, pacc
c
c ***
c *
c *   Shift the power density "pacc" kilowatts to the right.
c *
c ***
c
      do 10 i=1,npf
   10 pf(i)=pf(i)+pacc
c
c ***
c *
c *   The power density is apportioned between the engine and motor.
c *   The engine is used for topping.  The motor supplies all power
c *   requirements below pmax.
c *
c ***
c
c ***
c *
c *   Find the bin where pmax is located.  Call it k.
c *
c ***
c
      d=(pf(2)-pf(1))/2.
      do 15 i=1,npf
      if (abs(pf(i) - pmax) .le. d) goto 16
   15 continue
   16 k=i
c
c ***
c *
c *   Use the first k-1 bins of f and pf to create fm and pfm.
c *
c ***
c
      do 20 i=1,k-1
      pfm(i)=pf(i)
      fm(i)=f(i)
   20 continue
```

```
C
C ***
C *
C *   Apportion the kth bin between the motor and engine.
C *



C ***
C
      fm(k)=((pmax-pf(k)+d)/(2*d))*f(k)
      fe(1)=f(k)-fm(k)
C
      pfm(k)=(pf(k)-d+pmax)/2.
      pfe(1)=pfm(k)+d-pmax
C
C ***
C *
C *   Assign the motor a probability mass at pmax (simulating
C *   topping.)
C *
C ***
C
      sum=0.
      do 25 i=k+1,npf
      sum=sum+f(i)
   25 continue
      fm(k+1)=sum+fe(1)
      pfm(k+1)=pmax
C
C ***
C *
C *             The power requirements above pmax are handled by the engine.
C *
C ***
C
      do 30 i=k+1,npf
      j=i-k+1
      fe(j)=f(i)
      pfe(j)=pf(i)-pmax
   30 continue
C
C ***
C *
C *   Computed below are:
C *                             1. ds/hr before .8 discharge
C *                             2. l/hr before .8 discharge
C *                             3. l/hr after discharge
C *
C ***
C
C ***
C *
C *   ds/hr
C *
C ***
C
      do 35 i=1,npf
   35 tmp(i)=xirtrp(pfm(i),ps,s,nps)
      call matmul(tmp,fm,sbar,1,npf,1)
C
C ***
C *
C *   l/hr before discharge = .8
C *
C ***
```

```
c
      do 45 i=1,npf
   45 tmp(i)=xintrp(pfe(i),pl,xl,npl)
      call matmul(tmp,fe,xlbar,1,npf,1)
c



c ***
c *
c *   l/hr after discharge=.8
c *
c ***
c
      do 50 i=1,npf
   50 tmp(i)=xintrp(pf(i),pl,xl,npl)
      call matmul(tmp,f,xlbar2,1,npf,1)
c
c ***
c *
c *   Request average speed.
c *
c ***
c
      print 1, 'average speed?'
      read *, v
c
c ***
c *
c *   Compute distance until discharge=.8
c *
c ***
c
      h=.8/sbar
      ddis=h*v
c
c ***
c *
c *   Output: fuel consumption at distances 0 through 100 km.
c *   Fuel consumption at point of .8 discharge is also listed.
c *
c ***
c
      xldis=xlbar*h
c
      write (2,3) ddis, xldis
      write (2,4)
      do 55 i=1,10
      d=i*10.
      if (d .lt. ddis) then
      fc=d/v*xlbar
      else
      fc=xldis+(d-ddis)/v*xlbar2
      endif
      write (2,6) d, fc
   55 continue
c
      close(unit=1)
      close(unit=2)
c
c ***
c *
c *   Loop to top of program if user so directs.
c *
c ***
c
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
      print 1, 'another run?'
      read 7, ians
      if (ians .eq. iy) goto 8
c
      stop


      end
```

ADDENDUM TO DESIGN TRADE-OFF

STUDIES REPORT

ACCESSORY DRIVE AND ENERGY UTILIZATION
TRADE-OFF STUDIES

The NTHV accessory loads require a significant portion of the total power required to propel the vehicle. At low vehicle speeds, the accessory power is as much as 40 percent of the total power required. Table 1 shows typical accessory demand horsepowers for the NTHV. These accessory power demands have adverse effects both on the electric topped by diesel range and on the diesel fuel consumption rates. These additive effects cause dramatic fuel consumption variations, as shown in Figure 1. The accessory system tradeoffs were studied by first looking at different vehicle power sources, such as the heat engine, motor, regenerative braking, and waste heat recovery, to drive the accessories. Second, a parallel study covered the accessories themselves, namely the reduction in accessory power requirements by using controllable built-in power limiting devices, advanced air conditioning systems, and variable speed belt drives.

Table 1. NTHV Accessory Power Requirements At Two Different Accessory Driveline Speeds

Accessory Name	Power Requirement at 1000 RPM (kW)	Power Requirement at 2500 RPM (kW)
Fan	0.37	1.50
Water pump	0.15	1.19
Power steering pump	0.37	1.34
Alternator	0.60	1.27
Brake vacuum pump	0.15	0.75
Air conditioning compressor (average)	1.50	3.58
Transmission pump	0.15	1.04
Total	3.29	10.67

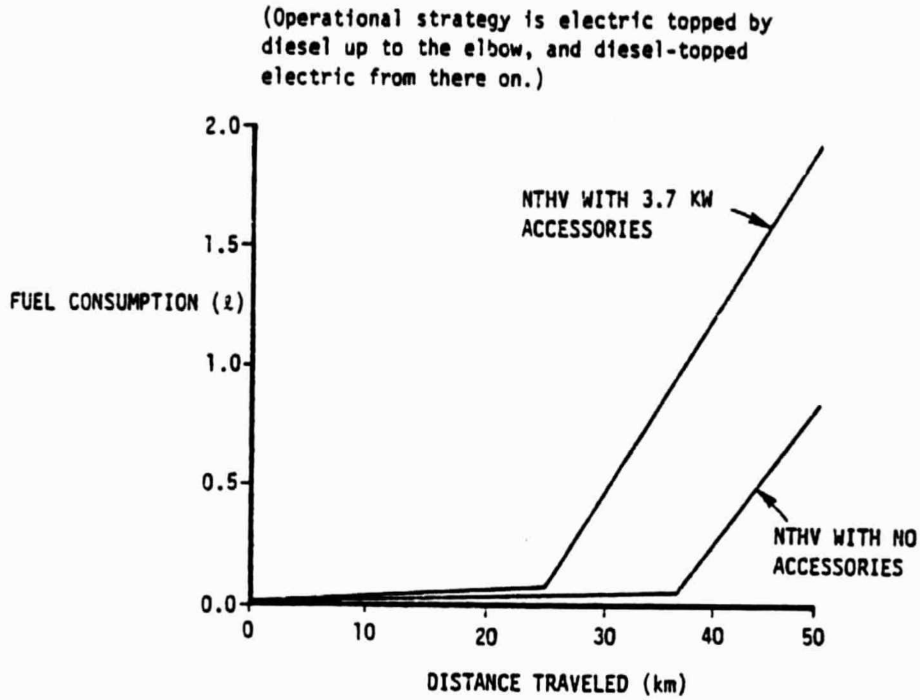

Figure 1. Effect of Accessory Power on NTHV Fuel Consumption

The different methods of driving the accessories from the available energy sources are:

1. Heat engine with parallel propulsion configuration (Figure 2).

2. Heat engine with an in-line propulsion configuration (Figure 3).

3. Operational strategy power output (Figure 4).

4. Motor (Figure 5).

5. Separate accessory motor (Figure 6) or separate engine.

6. Combined engine cooling and exhaust Rankine cycle (Figure 7).

7. Exhaust gas turbine accessory compounding (Figure 8).

8. Regenerative braking (Figure 9).

9. Flywheel (Figure 10).

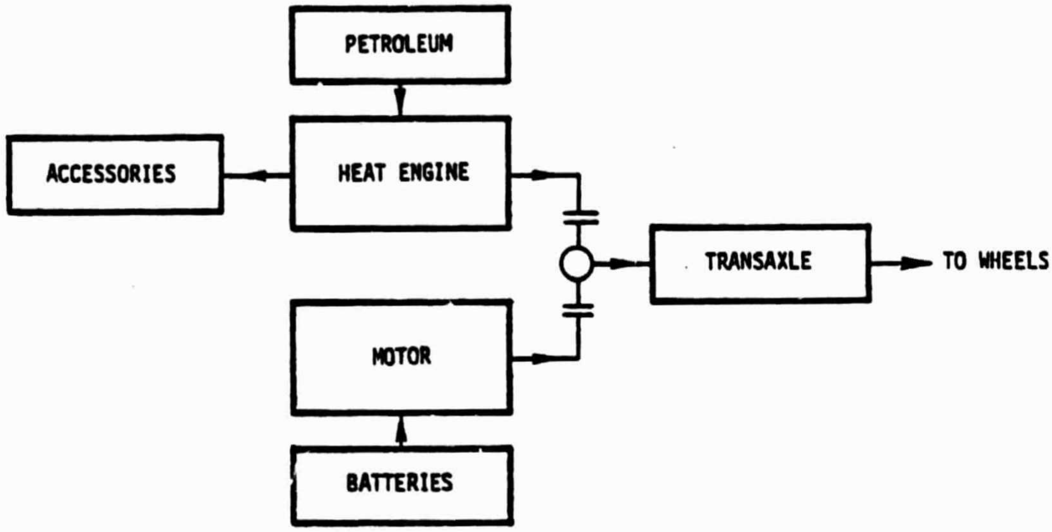

Figure 2. Heat Engine Accessory Drive Concept Using Parallel Propulsion Configuration

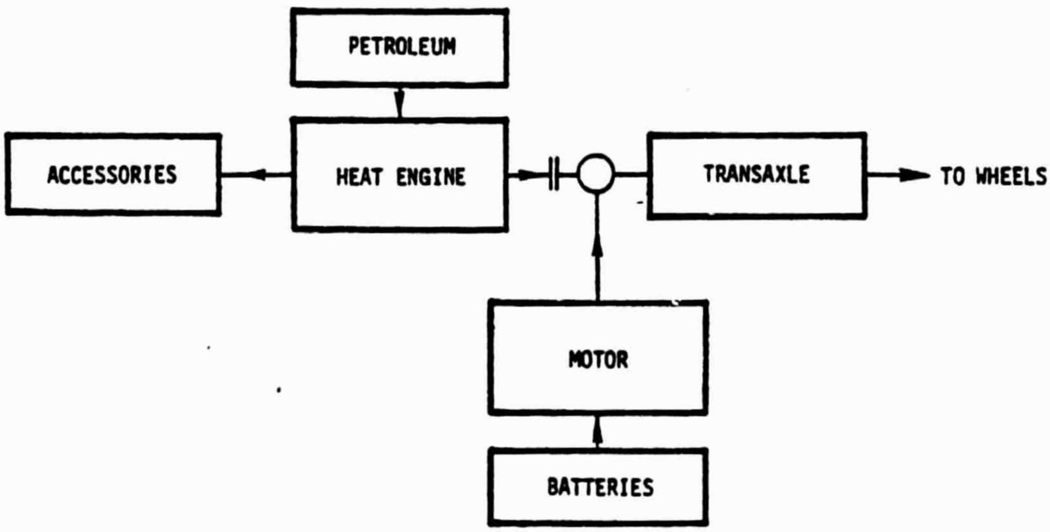

Figure 3. Heat Engine Accessory Drive Concept Using In-Line Propulsion Configuration

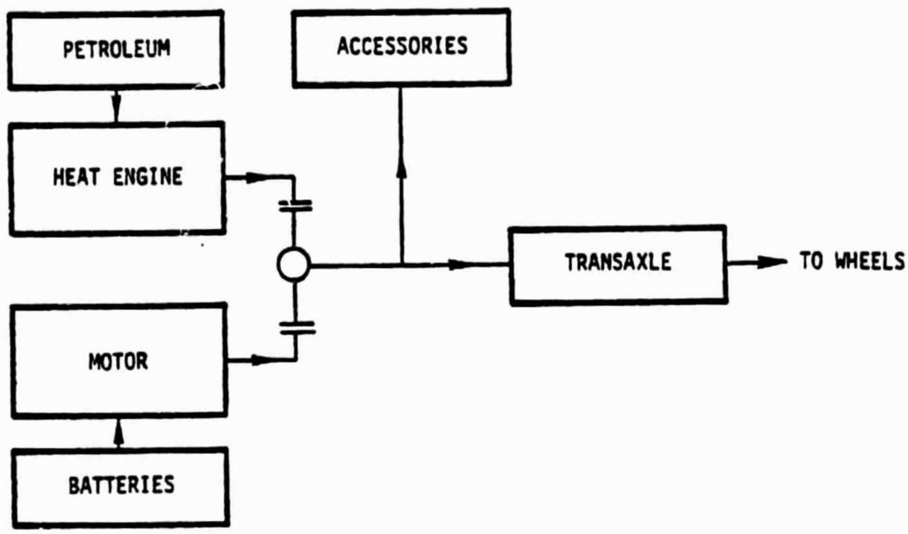

Figure 4. Operational Strategy Power Output Accessory Drive Concept

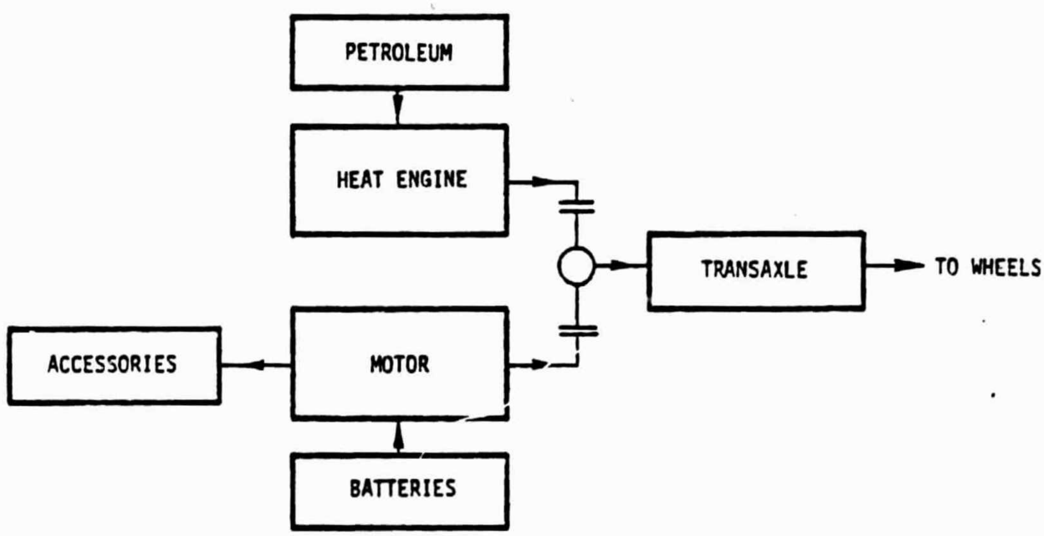

Figure 5. Motor Accessory Drive Concept

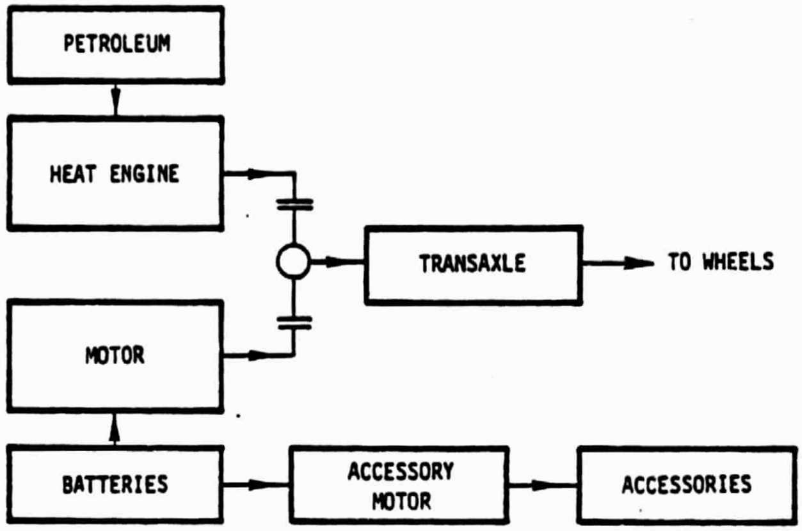

Figure 6. Separate Motor Accessory Drive Concept

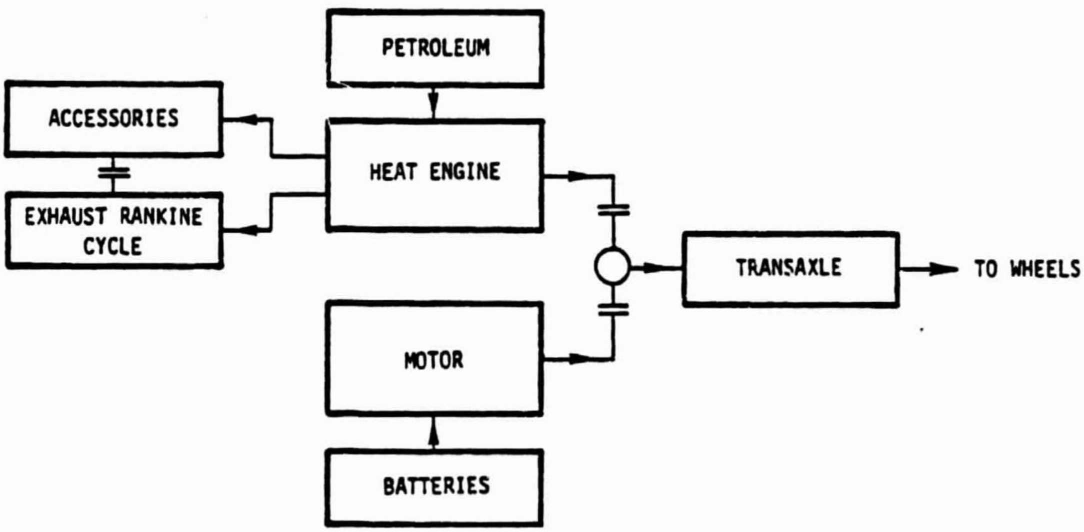

Figure 7. Exhaust Rankine Cycle Accessory Drive Concept

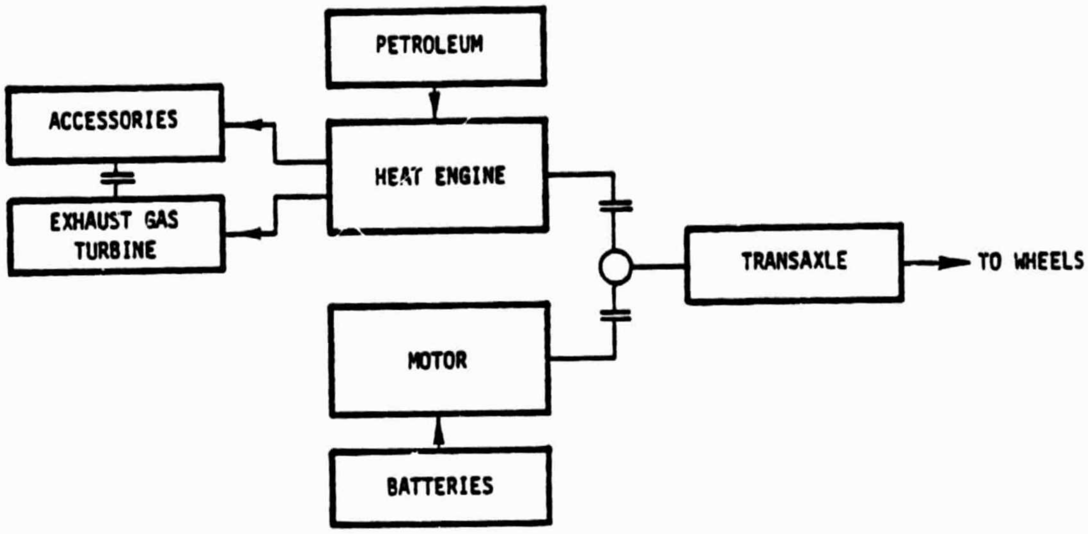

Figure 8. Exhaust Gas Turbine Accessory Compounding Drive Concept

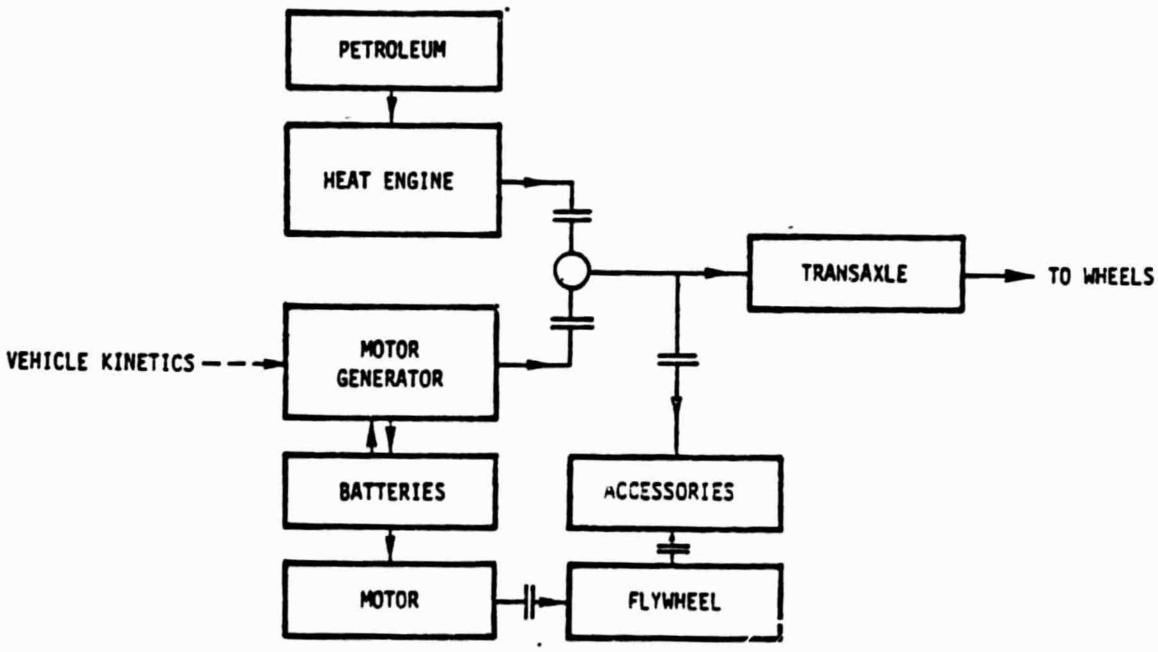

Figure 9. Regenerative Braking Accessory Drive Concept

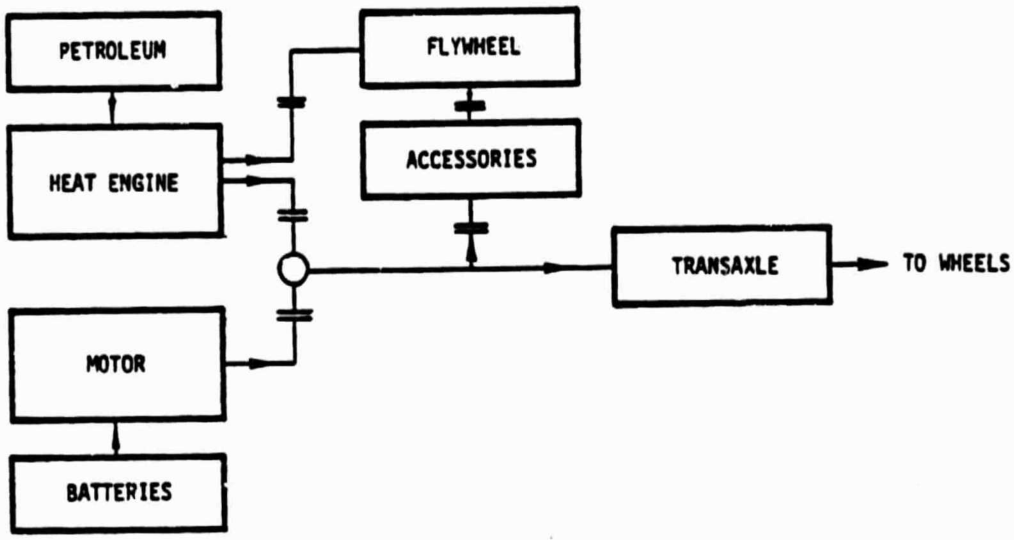

Figure 10. Flywheel Accessory Drive Concept

The accessory drive concepts were evaluated for performance, fuel economy improvement potential, cost, near-term availability, reliability and maintainability. The flywheel concepts have configuration complexities and high cost for driving the accessories. However, the recovery and reuse of braking energy is cost beneficial in the NTHV design, where the energy is used to charge the batteries. This yields a 5.6 percent improvement in fuel economy. Separate accessory motor or engine and turbo accessory compounding concepts produce no fuel economy improvements, but cause approximately a $300-increase in the purchase price of the NTHV.

The combined engine cooling and exhaust Rankine cycle can provide a 10 percent improvement in fuel economy for the diesel topped by electric mode operational strategy. But this means only 8.5 percent overall improvement in fuel economy. The variable heat engine loads and speeds of the NTHV lower the potential of using the exhaust waste energy as an accessory drive, but this variable energy source can be used to supplement the battery energy by charging (which will be discussed later in this addendum).

The recovered vehicle energy will come to the batteries both from regenerative braking and from waste heat. The two other possibilities for accessory drive are the engine and the operational strategy output — in which the power is taken from the driveline, so either the engine or the motor could drive the accessories. A comparison of different operational strategy scenarios for these two accessory concepts is given in Table 2. These results are obtained for a 50 percent city and a 50 percent highway driving combination, and the accessories are driven at constant rpm with a variable speed belt drive. The fuel economies show that the concept of running the engine all the time to drive the accessories is more fuel consuming than the operational strategy accessory drive concept. The fuel consumption versus distance traveled behaviors of these two accessory drive concepts are shown in Figures 11 and 12.

Required NTHV Accessories

The NTHV requires a cooling fan, water pump, power steering pump, alternator, brake vacuum pump, transmission pump and air conditioning compressor as accessories. These accessories were studied individually in an attempt to reduce their load requirements. The air conditioning compressor is the highest power consumer of the accessories, and it will be discussed in detail in the next section.

The cooling fan is used primarily at low crankshaft rpm. To prevent excessive power consumption, the fan should be run at 1,000 rpm, and its operation should be controlled by an on-off clutch, depending on the temperatures of the propulsion components. The rpm of the fan should be stepped up or down by using a variable speed accessory drive.

The water pump should be powered by the accessory drive system because the water pump will be used to circulate the engine coolant for heating, even when the NTHV is being driven only by the motor. The power requirements of the water pump are almost linear with its speed, which should be controlled for the required flow rates.

Table 2. The Comparison of Different Operational Strategies in Different Missions for the Heat Engine Accessory Drive with In-line Propulsion Configuration and for the Operational Stragegy Accessory Drive

NTHV Description	Electric Topped by Diesel Range [km (miles)]	Fuel Economy [km/ℓ (mpg)] Mission A	Fleet Travel	Short Week, Long Weekend Travel
1. Reference ICE vehicle with constant 3.7 kW (5 hp) accessories	--	11 (27)	11 (27)	11 (27)
2. X-body with T/C diesel and constant 3.7 kW (5 hp) accessories	--	17 (40)	17 (40)	17 (40)
3. Parallel NTHV propulsion configuration with no accessories	36 (23)	47 (111)	37 (87)	33 (78)
4. Parallel NTHV propulsion configuration with operational strategy accessory drive and constant 1.5 kW (2 hp) accessories. Engine is used only for topping the motor when the motor is the primary drive component.	29 (18)	35 (82)	31 (73)	30 (71)
5. Parallel NTHV propulsion configuration with operational strategy accessory drive and constant 3.7 kW (5hp) accessories	25 (15)	26 (62)	25 (59)	26 (60)
6. In line NTHV propulsion configuration with heat engine accessory drive, maximum engine torque = 4.16 m-kg (30 ft-lbf) and constant 3.7 kW (5 hp) accessories	81 (51)	18 (43)	17 (41)	17 (41)
7. In line NTHV propulsion configuration with heat engine accessory drive, maximum engine torque = 2.08 m-kg (15 ft-lbf) and constant 3.7 kW (5 hp) accessories	45 (28)	21 (49)	19 (44)	18 (42)

Table 2. (cont'd)

NTHV Description	Electric Topped by Diesel Range [km (miles)]	Fuel Economy [km/ℓ (mpg)] Mission A	Fuel Economy [km/ℓ (mpg)] Fleet Travel	Fuel Economy [km/ℓ (mpg)] Short Week, Long Weekend Travel
8. In line NTHV propulsion configuration with heat engine accessory drive, maximum engine torque = 2.08 m-kg (15 ft-lbf) up to 2000 rpm, becoming zero at 2500 rpm, and constant 1.5 kW (2 hp) accessories	32(20)	19 (46)	18 (44)	18 (43)
9. In line NTHV propulsion configuration with heat engine accessory drive and constant 3.7 kW (5 hp) accessories. The engine is also used for accelerating the vehicle 0→16 km/hr and for topping, with the electric motor as the primary drive component.	38 (24)	17 (39)	16 (38)	16 (38)
10. In line NTHV propulsion configuration with heat engine accessory drive and constant 1.5 kW (2 hp) accessories. The engine is also used for accelerating the vehicle 0→16 km/hr and for topping, with the electric motor as the primary drive component.	38 (24)	20 (46)	18 (43)	18 (43)
11. In line NTHV propulsion configuration with disengaged heat engine for accessory drive and constant 3.7 kW (5 hp) accessories. The engine engages to the propulsion system for accelerating the vehicle 0→16 km/hr and for topping, using the electrical motor as the primary drive component.	38 (24)	21 (50)	20 (46)	19 (44)

Table 2. (cont'd)

	Electric Topped by Diesel Range [km (miles)]	Fuel Economy [km/ℓ (mpg)]		
		Mission A	Fleet Travel	Short Week, Long Weekend Travel
12. In line NTHV propulsion configuration with disengaged heat engine for accessory drive and constant speed 1.5 kW (2 hp) accessories. Engine is running all the time. The engine engages to the propulsion system for accelerating the vehicle 0 16→km/hr and for topping, using the electric motor as the primary drive component.	38 (24)	25 (59)	25 (52)	21 (49)
13. In line NTHV propulsion configuration where the engine engages to the propulsion system for accelerating the vehicle 0→16 km/hr and for topping. Engine starts and stops 18 times during FUDC. The motor is always on-line with the propulsion system, and the constant 1.5 kW (2 hp) accessories are driven by the operational strategy drive shaft.	31 (19)	34 (80)	30 (70)	29 (67)

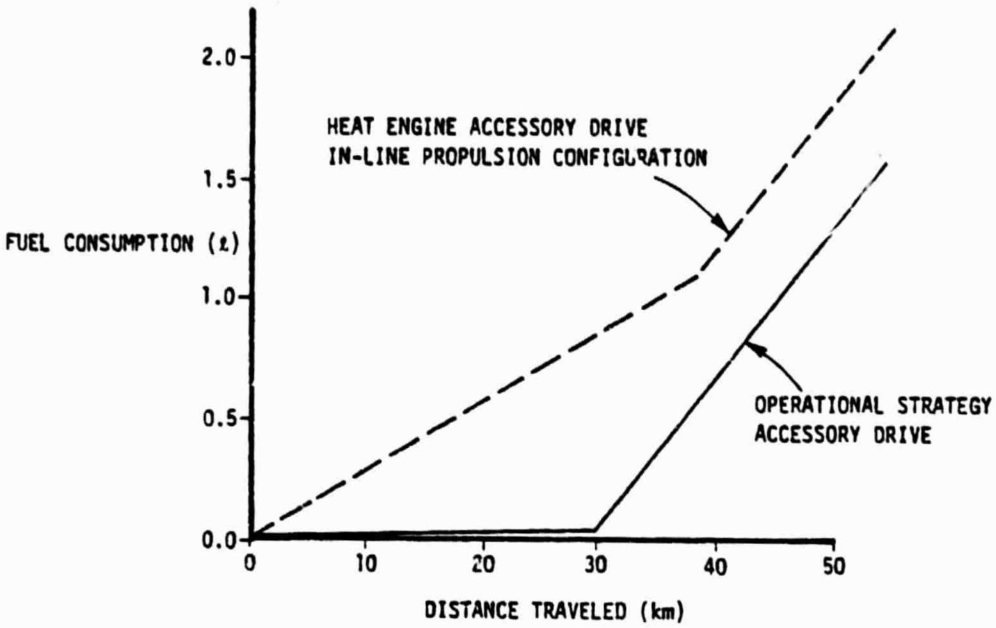

Figure 11. Fuel Consumption Versus Distance Traveled Behavior for Two Accessory Drive Concepts, 1.5 kW Accessory Power (Constant)

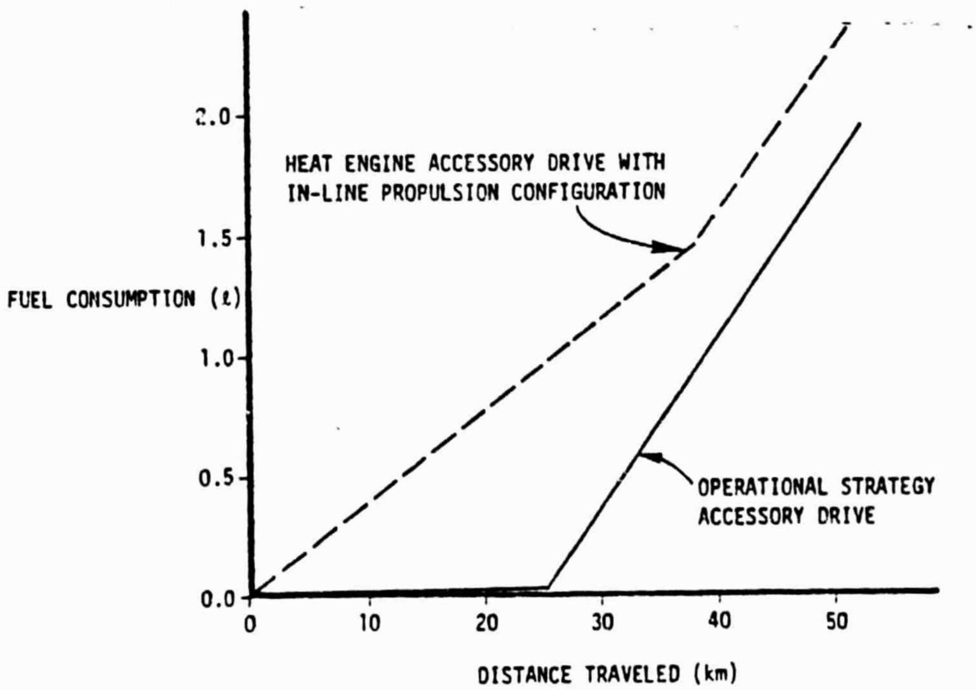

Figure 12. Fuel Consumption Versus Distance Traveled Behavior for Two Accessory Drive Concepts 3.7 kW Accessory Power (Constant)

The power steering pump is needed to provide the oil pressure for the power steering, which primarily is used at low speeds. The power steering pump has a built-in limiting device (a flow limiter) to reduce power requirements under no-load conditions.

The NTHV can operate without an alternator. Present-day alternators are sized to give adequate output at low rpm. Typically, they run at two to three times the crankshaft speed; but the fact that the NTHV has an alternate energy source, the batteries, gives us the opportunity to use a dc-dc converter instead of an alternator. This choice will save approximately 0.6 kW (0.8 hp) at low crankshaft rpm.

The brake vacuum pump is needed for the standard vacuum brake booster system of the X-body vehicle. Since neither the diesel engine nor the electric motor produce vacuum, the vacuum must be produced with a pump. The brakes could also be powered by hydraulic boost from the power steering pump, with no effect on the performance of the power steering system. Both approaches require the same amount of power, but the hydro-boost brake system can cope with higher braking pressures.

The NTHV uses a 3-speed automatic transmission. The transmission pump, which is a variable displacement pump, uses 0.15 kW (0.2 hp) at low crankshaft rpm. Using a manual transmission would be one way of conserving this power loss.

Air Conditioning

A vehicle of the size and price class of the NTHV will be expected to have an air conditioning system, but the air conditioning compressor is the highest power consumer of all of the accessories. In today's energy conscious public, if a driver were made aware of the penalty in fuel economy when the air conditioner is turned on, there would be less usage (and more efficient usage) of air conditioners. There are several concepts, as shown in Table 3,to cool the passenger and battery compartments in an NTHV.

Table 3. Air Conditioning Concepts Applicable to an NTHV

Concept Description	Energy Source
Variable displacement Freon compressor system	Heat engine and electric motor
Rankine cycle turbo-compressor	Exhaust waste heat
Absorption ammonia-water	Exhaust waste heat or fuel burning heater
Air-cycle	Heat engine and electric motor

If these concepts are compared on the basis of performance and fuel economy improvement, one finds a firm advantage for the operational strategy driven and variable delivery freon compressor air conditioning system. The exhaust waste recovery concepts do not produce sufficient cooling capacity: only 1610 kW (6440 Btu/hr). Absorption air conditioning uses about seven times the heat exchanger area that compressor air conditioning uses. Varying diesel engine exhaust temperatures (shown in Figure 13) and unfavorable idle conditions are problems for the use of exhaust waste energy for cooling. The air cycle machines produce adequate performance with good cooling capacity, but consume power and reduce the fuel economy.

The NTHV should be equipped with a variable delivery air conditioning compressor that exhibits only moderately fast cool down capability. With this approach, the average power requirements of the air conditioning compressor can be as low as 1.1 kW (1.5 hp) at low crankshaft rpm.

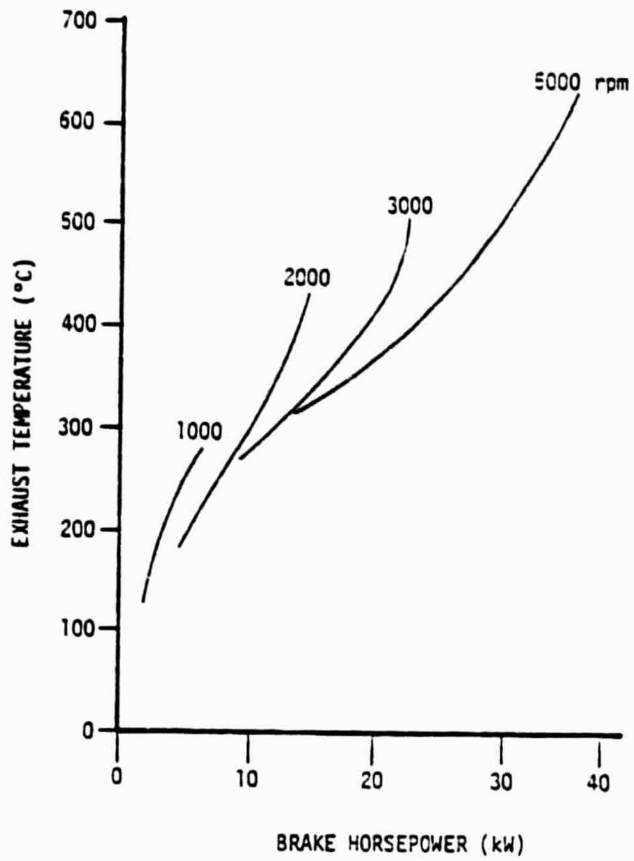

Figure 13. Volkswagen Diesel Exhaust Temperature Survey,
90 cid Naturally Aspirated

Accessory Drives

All the accessories are designed to perform adequately at low crankshaft rpm. But as the rpm increases, the accessory power requirements increase much faster than the added performance. Therefore, constant speed accessory drives are a definite advantage. The fuel economy improvement potential of constant accessory drives in a NTHV can be as high as 30 percent. The constant speed accessory driveshaft can be driven either by a constant speed motor or by a variable belt drive. The two drive concepts have similar reliabilities, but the variable speed belt drive has the strong advantage that either power plant can drive the accessories with a speed ratio of up to four-to-one. If one of the propulsion drive components fails, the accessories could still be driven by the other.

NTHV Accessory Conclusions

1. All of the accessories of the NTHV should be driven by the operational strategy power output using a variable speed drive. The variable speed drive should have a controllable step up and step down capability.

2. Each accessory should be studied and tested carefully, and the ones with the lowest power requirements should be used. These should be driven through on-off clutches that are controllable for intermittent operation, if possible. Accessory drive strategies and load matching techniques should be controlled by an accessory control function of the auxiliary microprocessor.

3. The maximum NTHV accessory power requirements at low crankshaft rpm are for the:

Fan	0.37 kW
Water pump	0.15
Power steering pump	1.37
Brake vacuum pump	0.15
Air conditioning compressor	1.11
Transmission pump	0.15
Total	2.30 kW (3.10 hp)

4. A 2.3 kW (3.1 hp) maximum accessory power requirement for the NTHV can be lowered significantly, to about 1.5 kW (2 hp), by computer controlled load matching and operational strategies. The Minicars' NTHV with this accessory system will have a fuel economy of 35 km/ℓ (82 mpg).

NTHV Heating System Concepts

The heating system of the NTHV must perform two different functions: to heat the battery compartment and to heat the passenger compartment and defrost the windshield. The heating system should be usable in all modes of the NTHV operational strategy. Several heating system concepts have been evaluated for fuel economy, cost, and reliability. These are

1. The engine waste heat to the cooling water is used during diesel operation, and batteries are used during motor operation.

2. The engine waste heat to the cooling water is used during diesel operation, and a separate petroleum burning heater is used all other times.

3. The engine waste heat to the exhaust is used during diesel operation, and a separate petroleum burning heater is used all other times.

4. The engine waste heat to the cooling water is used during diesel operation, and the heat stored in the cooling water (or in another feasible medium) at night during battery charging is used during motor operation. If the stored heat is depleted, then the engine is started in order to heat the cooling water.

The engine cooling water is used as an energy carrier at all times; the water is driven by the water pump from the accessory drive system. The engine cooling water heating system is shown in Figure 14.

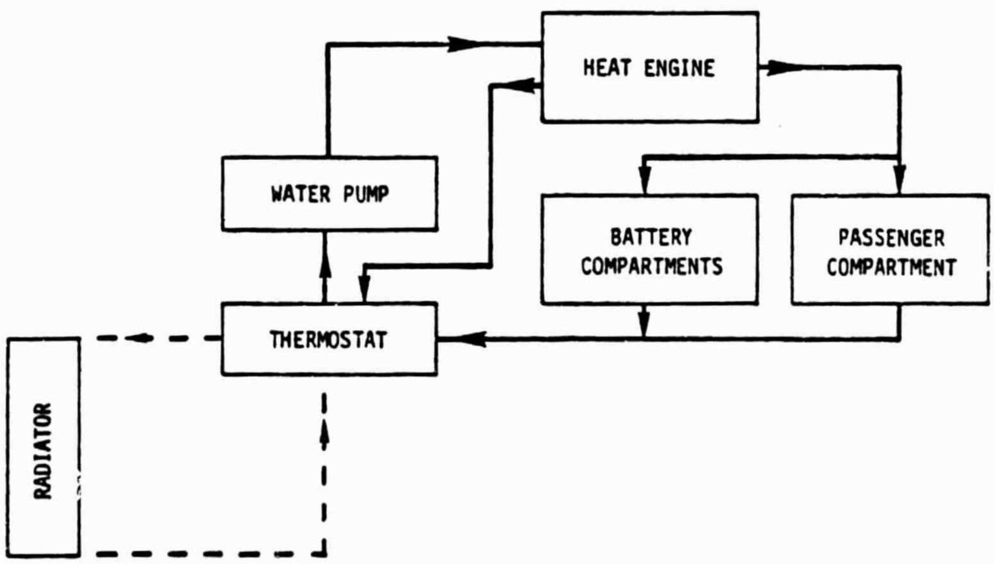

Figure 14. Schematic of the NTHV Heating System

If electrical energy is used to heat the cooling water during the electric topped by diesel mode, the range for that mode will decrease by 45 percent, thereby eliminating that possibility. Using a separate petroleum burning heater during the electric-mode operation could consume 27 liters of petroleum per year in 0°C environment. The fuel burning heater is a cost effective and reliable heating system for the NTHV.

The exhaust waste energy, which is available at an average of 340°C, is a good heat source for the heating system. But exhaust gases also have sufficiently high temperatures and flow rates for other types of energy recovery, such as an exhaust turbine/alternator combination to supplement battery charging. The lower temperature waste heat source, the engine coolant, can still be used effectively in the heating system.

Storing heat in the NTHV during the nightly charging operation can be a feasible way of supplying the heating system for non-diesel operation. If the coolant water is used as a heat source, 105 liters of water is required for heating during motor operation. If a light and compact heat storage medium can be designed for the NTHV, it would be feasible to use wall plug electricity for heating.

The heating concepts were rated for fuel economy improvement, cost, weight, and complexity. The fourth concept was found to be the best, except for cold climates, when a combustion heater should be used during motor operation.

NTHV for Cold Climates

There is always the question of whether there should be a different NTHV design for cold climates. The cold-weather problems of an NTHV are the following:

1. The battery system will lose 60 percent of its capacity if the battery temperature drops to -20°C.

2. The diesel engine has poor cold-weather starting capability at -30°C. The diesel engine will consume 0.032 liters more fuel for each cold start.

3. Diesel engine topping will require preheating the engine, or the topping power won't be available in one to two

seconds, when it is needed. This will consume 23 liters more fuel a year in a 0°C winter environment.

4. The passenger compartment will need more heating.

There are several design approaches to remedy these cold-weather problems: the battery and powertrain compartments can be well insulated for cold-weather operation; the batteries and the powertrain can be heated during the nightly battery recharging process for a warm start in the morning; also, the heating requirements of the passenger compartment can be reduced by 31 percent with an airtight and well insulated interior design. The cost effective solutions are the battery and powertrain insulation, the nightly heating of the batteries and the engine, and, of course, a combustion heater for motor operation in the cold climates.

Waste Energy Recovery in an NTHV

The deceleration energy and waste heat can be used to improve the fuel economy of an NTHV. The deceleration energy is available in an intermittent manner. The exhaust waste energy is available at high temperature and varies considerably with engine speeds and loads. These waste energies are best utilized to recharge the traction batteries. The waste energy in the engine cooling water is available at low temperatures, which are appropriate for heating.

The recovery and reuse of deceleration energy, i.e., regenerative braking, is discussed in detail in the Preliminary Design Data Package and in the main text of the Trade-Off Studies. Our overall findings rate regenerative braking energy recovery as cost effective; the improvement in petroleum economy is 5.6 percent.

The exhaust gases are available at an average temperature of 340°C and an average mass flow rate of 110 kg/hr. There are several potential methods of regaining this waste energy, but only three seem to merit consideration: a Rankine bottoming cycle, a turbo-compound diesel, and an exhaust turbine.

The Rankine bottoming cycle is difficult to implement into an NTHV because of the component size and complexity. The turbo-compound system geared to the crankshaft cannot provide major gains in engine efficiency because of the large variations in engine speed and load.

In the diesel-electric hybrid, there is a more promising way to utilize the exhaust waste energy. A turbine driven generator can return the recovered waste energy to the traction batteries. The recovered energy can be stored in the batteries and used for electric topping in the diesel operating mode, and, when enough energy is stored, the vehicle can revert to the electric driving mode with diesel topping. Figure 15 shows a possible system for energy recovery through a turbine driven generator.

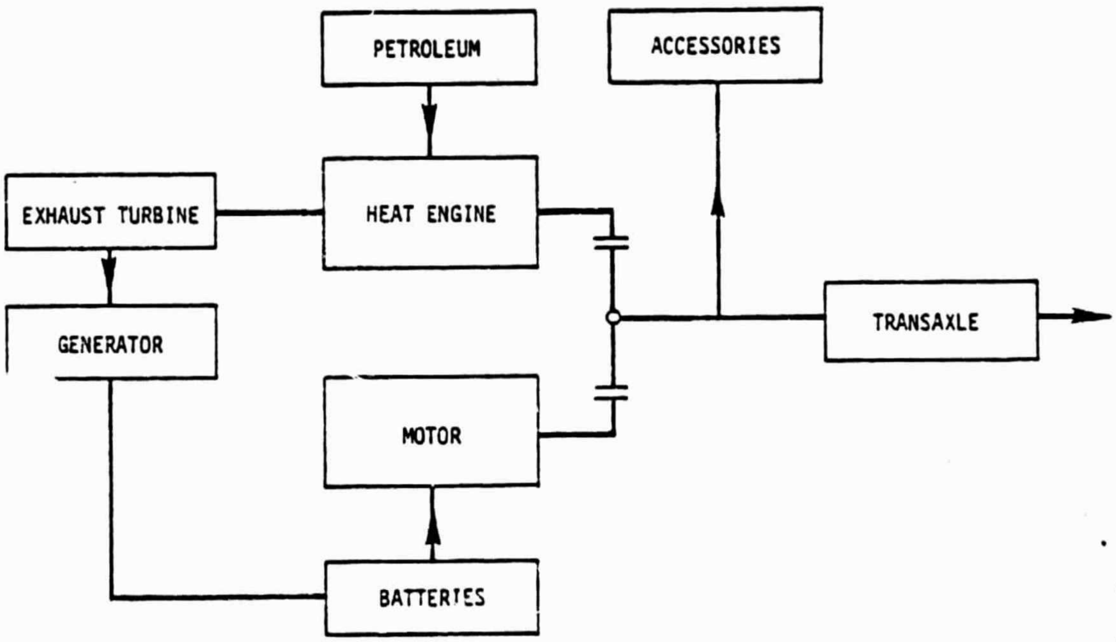

Figure 15. Exhaust Waste Energy Recovery in an NTHV Using a Turbine Driven Generator System

The extensive usage of turbochargers in vehicles has caused the cost of small turbines to decrease sufficiently that a turbine driven generator can be cost effective in the near term. In the highway driving cycle, the exhaust waste energy is over 9 kW/hr. The recovery efficiency of this energy using a turbine driven generator is 30 percent. The range of the electric topped by diesel mode increases by 16 percent, resulting in an overall 12 percent improvement in petroleum economy.

Different Hybrid Configurations and Operational Strategies

The hybrid's fuel economy improvement depends strongly on its propulsion system configuration and operational strategy. Several different hybrid configurations with different operational strategies were studied; the results of these studies are presented in Table 2 above.

The Reference ICE vehicle is expected to have a fuel economy of 11 km/ℓ (27 mpg) in 1985. This vehicle consumes 1705 liters of fuel per annum. An X-body with a turbocharged diesel engine, on the other hand, would have a fuel economy of 17 km/ℓ (40 mpg) and consumes 1103 liters of fuel per annum. These two Reference ICE vehicles are listed in Table 2 (Items 1 and 2) for comparison to the NTHV configurations.

The highest fuel economy for an NHTV is achieved with a parallel propulsion system and no accessories (Item 3). For a 50/50 percent split of FUDC and FHDC, the proposed NTHV would have a 47 km/ℓ (111 mpg) fuel economy and consume 399 liters of fuel per annum. Therefore, the proposed NTHV design can better the fuel consumption of the Reference ICE vehicle by, at most, 77 percent.

When the accessories are added in, the proposed parallel configuration experiences a significant reduction in fuel economy. Even if the accessories are run at constant speed, a 1.5 kW accessory load degrades the fuel economy to 35 km/ℓ (82 mpg) and a 3.7 kW accessory load to 26 km/ℓ (62 mpg). In these configurations (Items 4 and 5 in Table 2), the accessories are run from the operational strategy output (that is, the accessory load is added to the road load and the total load is powered by the motor, the engine, or by both).

A simpler NTHV configuration is the in-line configuration, in which the propulsion components are in series (Items 6, 7 and 8). Running the engine all the time lowers the fuel economy to 19 km/ℓ (46 mpg). The application of different torque limiting factors to the engine varies the fuel economy by about 10 percent. In the in-line hybrid configuration, the engine torque requirements can be lowered to accommodate only the accessories, the 0→16 km/hr vehicle accelerations, and the toppings, when the motor is the primary drive component. This scenario does not improve the fuel economy. These are Items 9 and 10 in Table 2.

The fuel economy of the in-line configuration is improved by the engine disengagement capability. In the electric only mode the engine is disengaged from the rest of the propulsion system to power the accessories at 1,000 rpm. For accelerating the vehicle from 0 to 16 km/hr (18 times in FUDC) and for topping the motor, the engine is engaged to the propulsion system. This configuration (Items 11 and 12) improves the NTHV fuel economy to 25 km/ℓ (59 mpg).

An NTHV propulsion configuration similar to the parallel propulsion configuration is the in-line propulsion configuration in which the engine can be engaged or disengaged from the rest of the propulsion system, depending upon the operational strategy. The electric motor is always in-line with the propulsion system and the accessories are driven by the driveshaft of the propulsion system through a variable speed belt at 1,000 rpm (Item 13). This propulsion system exhibits as good fuel economy as the parallel NTHV propulsion configuration, 34 km/ℓ (80 mpg).

In summary, Item 4, the parallel NTHV configuration, and Item 13, the in-line NTHV configuration with engine disengagement capability exhibit similar fuel economies (both having operational strategy accessory drives). Consumer acceptance, the complexity of design, and the risk of design implementation should be the deciding factors in making a choice between the two configurations.